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IMPROVING EFFECTIVENESS AT REGIONAL REPAIR CENTERS THROUGH SIMULATION AND CUSTOMER SATISFACTION MEASUREMENTS

by

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June 1995

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The results of the simulation show that the PRRC has the capacity to successfully accomplish all surface ship pump maintenance without significant backlogs in the awaiting maintenance queue. A measure of effectiveness (MOE) for the PRRC is its timeliness in response to its customer's demands. Using the simulation model the PRRC managers can continuously improve customer satisfaction by reallocating resources to reduce pump TATs and provide a more accurate promised delivery date (PDD).

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS, ACRONYMS, AND ABBREVIATIONS

ACT	Actual Completion Time
ADT	Administrative Delay Time
BCR	Beyond Capability Repair
BSC	Beyond Shipboard Capability
CASREP	Casualty Report
CINC	Commander in Chief
CINCPACFLT	Commander in Chief, U.S. Pacific Fleet
CNO	Chief of Naval Operations
CO	Commanding Officer
COMNAVAIRPAC	Commander Naval Air Forces Pacific
D-level	Depot Level Maintenance
DBOF	Defense Business Operating Fund
DD	Destroyer
DDG	Guided Missile Destroyer
DOD	Department of Defense
DSRA	Dry-dock Selected Restricted Availability
ECT	Estimated Completion Time
ESC	Executive Steering Committee
FFG	Guided Missile Frigate
FISC	Fleet and Industrial Supply Center
FMO	Fleet Maintenance Officer
FSC	Fleet Scheduling Conference
FSQMB	Fleet Support Quality Management Board
FY	Fiscal Year
I-level	Intermediate Level Maintenance
IFMM	Integrated Fleet Maintenance Model
Lambda	Failure Rate
LDT	Logistics Delay Time

LVF	Lowest Value First
MOE	Measure of Effectiveness
MSQMB	Maintenance Support Quality Management Board
MTBF	Mean Time Between Failure
Mu	Mean Time Between Failure (Mu = 1/Lambda)
NEC	Navy Enlisted Classification
NUWC	Naval Undersea Warfare Center
O-level	Organizational Level Maintenance
OPTEMPO	Operational Tempo
OPTEST	Operational Test
P&E	Planning and Estimation
PACNORWEST	Pacific Northwest
PAT	Process Action Team
PDD	Promised Delivery Date
PRRC	Pump Regional Repair Center
PRT	Physical Readiness Test
PSNS	Puget Sound Naval Shipyard
QA	Quality Assurance
RDD	Required Delivery Date
RMC	Regional Maintenance Center
RRC	Regional Repair Center
SIMA	Ship Intermediate Maintenance Activity
SIMAN	SIMulation ANalysis
SRA	Selected Restricted Availability
SUPSHIP	Supervisor of Ships
SYSCOM	Systems Command
TAT	Turn Around Time
TRF	Trident Repair Facility
TRIPER	Trident Planned Equipment Repair
TYCOM	Type Commander
WIP	Work-in-Process

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I. INTRODUCTION

A. BACKGROUND

The National Performance Review (NPR) began on March 3, 1993 when President Clinton announced a six month review of the federal government and asked Vice President Gore to lead the effort. Its goal was to identify problems and offer solutions and ideas for savings. In remarks announcing the National Performance Review on March 3, 1993, President Clinton stated, *"Our goal is to make the entire federal government both less expensive and more efficient, and to change the culture of our national bureaucracy away from complacency and entitlements toward initiative and empowerment. We intend to redesign, to reinvent, and to reinvigorate the entire national government."* [Ref. 1] This ambitious initiative "to do more with less" by the President has rippled through the entire federal government, including the Department of Defense (DOD) and the Department of the Navy (DON).

B. WHY EXAMINE NAVY MAINTENANCE?

In response to the National Performance Review, the Navy has commenced a major initiative to save money and become more efficient by streamlining its industrial infrastructure. According to Admiral Mike Boorda, Chief of Naval Operations (CNO), the Navy's goal is "*... to size a region's ashore industrial infrastructure to eliminate excess capacity. We [Navy flag officers] must continue from where BRAC [Base Realignment and Closure Commission] decisions have taken us. We [Navy flag officers] must*

aggressively reduce the footprint and cost of our industrial capability..." [Ref. 2]

In order to streamline its industrial infrastructure, the Navy has developed the Regional Maintenance Concept (RMC). This concept has led to the consolidation of repair facilities into Regional Repair Center (RRC) in order to minimize redundant maintenance capabilities and excess capacity.

Due to the criticality of pumps for ships, submarines, and aircraft to be operational, the authors decided to examine the newly formed PACNORWEST PRRC in order to find ways to improve effectiveness. Two management tools are developed: a simulation model and a measure of effectiveness. The simulation model allows PRRC managers to evaluate the repair process and make intelligent decisions concerning the allocation of limited resources. The measure of effectiveness allows PRRC managers and Planning and Estimating (P&E) to more accurately determine the date pump repair will be completed, and thereby improve customer satisfaction.

C. SCOPE OF THESIS

A graphical representation of the ship repair maintenance process is shown in Figure 1.

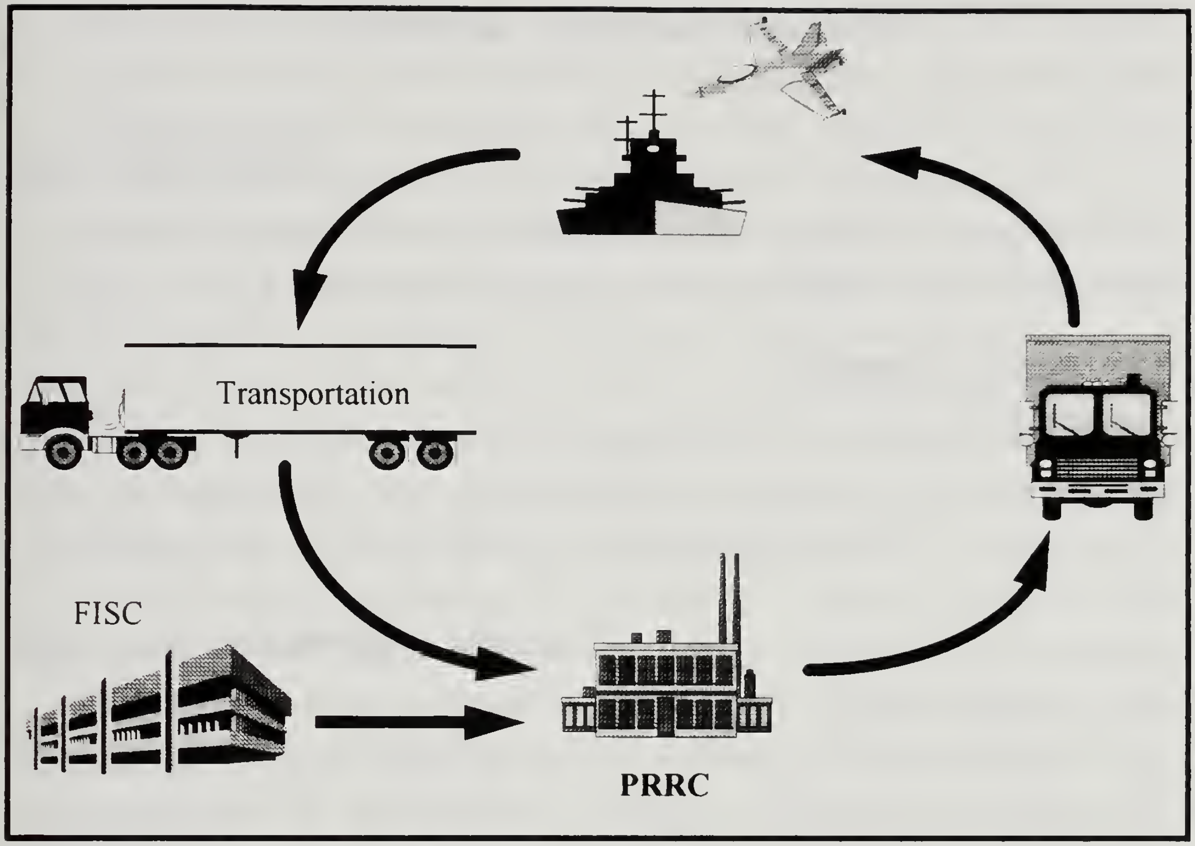

Figure 1. Repair Maintenance Process

The explanation of this figure is best served by an example. Onboard the USS Ford (FFG-54) a main feed pump fails. This pump is removed from the ship and sent to the Pump Regional Repair Center (PRRC), incurring transportation and logistics costs and time. At the PRRC it is repaired and then returned to the ship, again incurring transportation and logistics costs and time. Each part of this cycle, the ship, the round-trip transportation and logistics costs and time, and the PRRC, are areas that can be examined for potential savings and gains in efficiency.

The authors of this thesis examine the most critical part of this maintenance cycle, the operations of the PRRC.

Of all the elements in the repair maintenance cycle, the PRRC possesses the greatest potential for cost and time savings to achieve gains in efficiency and effectiveness.

The relationship and interaction between RRCs and Fleet and Industrial Supply Centers (FISCs) is currently being examined and is beyond the scope of this thesis.

D. THESIS OVERVIEW

This thesis is organized into seven chapters. This introduction is Chapter I. Chapter II is a description of "traditional" Navy maintenance as well as the new Regional Maintenance Concept. Chapter III discusses simulation modeling and Chapter IV describes the SIMAN simulation model for the PACNORWEST Pump Regional Repair Center. Chapter V introduces practical applications and embellishments of the PRRC simulation model. Chapter VI contains a discussion of measures of effectiveness and proposes a measure of customer satisfaction for the PRRC. Chapter VII provides the authors' conclusions and recommendations.

II. NAVAL SHIP MAINTENANCE

A. DISCUSSION

The purpose of this chapter is to provide background on "traditional" ship maintenance and the events leading to the Navy's decision to pursue a regional maintenance strategy for the fleet of the 21st Century. This chapter also describes the status of the execution of this strategy as well as discusses the establishment of the Pacific Northwest Pump Regional Repair Center (PACNORWEST PRRC).

B. SHIP MAINTENANCE LEVELS

Ships are complex structures that require constant care and upkeep. They operate at sea in a harsh and unforgiving environment. An uncared-for ship will quickly deteriorate and fail in its mission. Today's modern warships have the additional complexity of advanced weapon systems and gas turbine propulsion plants. In addition to performing demanding six month deployments and exercises, Naval vessels must be at the ready and able to respond to crises at any time and any place. To help ensure the ships of the fleet will be ready when called upon, the Navy invests in an extensive ship maintenance program. [Ref. 3]

The Navy ship maintenance program is designed to keep ships at "an adequate level of material condition to maximize their required operational availability to the Fleet Commanders". [Ref. 4] In other words, the goal of the maintenance program is to keep all shipboard equipment as well as the ships themselves in proper working order,

thereby maintaining maximum readiness. "Downtime" for any system or component is to be minimized.

The "traditional" Navy ship maintenance program has three levels, each requiring a different degree of capability. The levels are organizational (O-level), intermediate (I-level), and depot (D-level).

1. Organizational Level Maintenance

The first level of maintenance is the organizational level consisting of the ship itself and the sailors onboard the ship. Organizational level maintenance is that corrective and preventive maintenance accomplished by the ship's crew. The work is a blend of equipment operation, condition monitoring, planned maintenance actions, and repair ranging from simple equipment lubrication to component change out and, in some cases, complete rework in place. [Ref. 4] If the required maintenance is deemed to be beyond shipboard capability (BSC), it is referred to I-level maintenance.

2. Intermediate Level Maintenance

The second level of maintenance is the I-level consisting of submarine and destroyer tenders, repair ships, Shore Intermediate Maintenance Activities (SIMAs), and Naval Reserve Maintenance Facilities (SIMA NRMFs). At these commands Navy personnel with specialized facilities, training, and Navy enlisted classifications (NECs) accomplish intermediate level repair work.

Intermediate level maintenance is that maintenance which is normally performed by Navy personnel stationed on submarine and destroyer tenders, repair ships, and at SIMAs and SIMA NRMFs. It normally consists of calibration; repair

or replacement of damaged or unserviceable parts, components, or assemblies; the emergency manufacture of unavailable parts; and providing technical assistance. [Ref. 5] If the required maintenance is beyond capability repair (BCR), it is referred to D-level.

3. Depot Level Maintenance

Depot level maintenance is that type of maintenance generally requiring a greater industrial capability than possessed by either organizational or intermediate level activities. It consists of maintenance performed by shipyards, both Navy and private, Naval Ship Repair Activities, and shore based activities. Maintenance is usually performed on equipment requiring major overhaul or complete rebuild of parts, assemblies, subassemblies, end items, and complete platforms, including manufacture of parts.

The only work to be scheduled for depot level maintenance activities is work not feasible to be accomplished by organizational or intermediate level maintenance activities. This work is not feasible because of insufficient time or manpower, or because it is beyond the capability of these fleet maintenance activities, or because it is of such a nature that split responsibility between fleet and depot maintenance activities should be avoided. [Ref. 3,5]

C. REGIONAL MAINTENANCE STRATEGY

The "traditional" Navy ship maintenance program has served the ships of the fleet very well over the years. During the Reagan military buildup of the 1980s, maintenance money was abundant. Today, the financial reality is much

different. In a political environment of shrinking defense dollars, the Navy needs to maintain the high level of material readiness of its fleet with less maintenance funds. The development of a new maintenance strategy that focuses on the benefits of consolidation, the elimination of excess capacity, and the avoidance of redundancy is necessary.

The Chief of Naval Operations, Admiral Mike Boorda, states "... *the integrated nature of our Naval forces -- ships, submarine, aviation, and the systems that support them -- present us with a unique opportunity to demonstrate significant savings through this approach [Regional Maintenance].*" [Ref. 2]

Under charter of the Chief of Naval Operations Executive Steering Committee (CNO ESC), the Fleet Support Quality Management Board (FSQMB) and its subordinate Maintenance Support Quality Management Board (MSQMB) were created in early 1993. Their mission was to improve the quality of fleet maintenance support and to develop a transition strategy for moving toward the minimum, most efficient, fleet maintenance support infrastructure which would satisfy the Navy's needs into the 21st Century. This infrastructure rightsizing effort is imperative to maintaining force readiness. [Ref. 6]

Previously, naval maintenance policy was formulated within platform lines (e.g., frigates, destroyers, cruisers, etc.) and warfare areas (e.g., surface, aviation, and submarine). As each new weapon system was fielded, new maintenance support was introduced or the existing maintenance support infrastructure within that warfare area was modified to handle the new system. In the past little regard was given to existing maintenance capability and

capacity of the other warfare areas and whether the maintenance facilities of these other warfare areas could act in support of those maintenance functions that are common across all platforms. The MSQMB's vision for future naval maintenance policy and programs is the development of a "seamless functional support structure that optimizes the existing maintenance process commonality among all platforms." [Ref. 6]

1. Afloat Naval Maintenance

Commonality of the maintenance process across platforms can be illustrated by examining electronic repair at the battle force (afloat) intermediate maintenance level. Aviation and surface electronic repair, which have historically been separated by warfare community, are now consolidated within the battle group afloat. The commonality of the maintenance process has been exploited onboard the aircraft carrier with the development of an integrated electronic repair workcenter (e.g., workcenter OE15) that supports both air and surface weapon system repair. Regional Naval Maintenance is centered on the idea of using this successful example of common maintenance process afloat and establishing a mirrored process ashore.

2. Ashore Naval Maintenance

The same maintenance repair task conducted ashore on return from forward deployment is conducted in a much different manner. The difference in conducting maintenance ashore from afloat is that there are two separate maintenance repair facilities. The Naval Station has a Ship Intermediate Maintenance Activity (SIMA) and the Naval Air Station has an Aircraft Intermediate Maintenance Department

(AIMD). These repair facilities often perform identical work. This raises several questions: Does excess capacity exist? Can consolidation of repair facilities save resources and still provide quality and responsive repair? Hence, the birth of Regional Naval Maintenance.

D. REGIONAL NAVAL MAINTENANCE CONCEPT

Consistent with the goals of optimizing maintenance support resources and developing a new maintenance strategy, the MSQMB proposed the Regional Maintenance Concept. This concept features a single maintenance management process, which standardizes and enhances the battle force intermediate maintenance capability afloat, and adopts a regional maintenance support strategy for all naval maintenance ashore. Through a single regional manager, all industrial facilities are sized for optimal utilization with the primary focus on the material readiness of the deploying battle group.

Under a regional maintenance strategy, a ship with a faulty electronic black box and an aircraft with a faulty avionics black box could send their equipment to the same shore repair facility, the Regional Maintenance Center (RMC).

According to Admiral Boorda, the Navy's goal "... is to have our ship and aviation maintenance and logistics support processes become more similar by taking advantage of the best practices that we can identify. We must evolve to the same processes through smart planning when there is a clear benefit to the fleet in terms of lower costs and improved readiness." [Ref. 2]

The Regional Naval Maintenance strategy supports this goal through several important objectives. These objectives include eliminating excess infrastructure, integrating supply and maintenance, developing compatible data systems, and continuously improving the maintenance process. Another important objective is to preserve the following: Systems Command (SYSCOM) technical control, responsiveness to the fleet, life cycle support, and readiness of the fleet. The task at hand is to take this strategy and develop a plan to meet these objectives. [Ref. 6]

E. REGIONAL NAVAL MAINTENANCE PHASED EXECUTION

In February 1994 the Naval Regional Maintenance Plan with its phased execution was presented to and approved by the CNO ESC. The plan was divided into three phases: Phase One FY 95-96, Phase Two FY 96-97, and Phase Three FY 97-98.

The primary task of Phase One is to optimize intermediate level interoperability by process improvement, by minimizing redundant capability and capacity, and by resource sharing under the management of the Fleet Maintenance Officers (FMOs). Also, prototype centers of excellence, called Regional Repair Centers (RRCs), are to be established as tests sites for future Phase Two integration of intermediate and depot level work.

Phase Two will integrate I-level and D-level activities with the establishment of Regional Maintenance Centers (RMCs) consisting of a group of Regional Repair Centers (RRCs).

In Phase Three, fleet maintenance is to be conducted using a single maintenance process supported by a common data foundation between fleets and by common production and

business practices. The Integrated Fleet Maintenance Model (IFMM) is currently under development and once complete it will be the cornerstone to the single maintenance process. [Ref. 6]

1. Overview of Implementation

The Regional Naval Maintenance Plan commenced FY 95 under the leadership and direction of the Fleet Maintenance Officers. Pilot projects and prototype studies commenced in April 1995 to ensure intermediate level consolidation and interoperability are proceeding smoothly. Phase Two regions have been identified and interim coordinators have been designated. At the January 1995 Commanders-in-Chief Conference, the CNO approved commencement of Phase Two on October 1, 1995, for the pilot integration and consolidation of intermediate and depot level maintenance in the Northwest and Mid-Atlantic regions. The proposed Regional Maintenance Centers to start operations in Phase Two are located at the concentrated areas in Figure 2:

Pacific Fleet	Atlantic Fleet
Pearl Harbor	Northeast
San Diego	Central
PACNORWEST	Southeast
WESTPAC	Ingleside

Figure 2. Proposed RMCs to Start Operations in Phase Two

2. Phase Two Implementation Challenges

Two very important issues come to the forefront with the commencement of Phase Two integration of intermediate and depot level maintenance into a single level maintenance structure ashore. The first issue is the need for a

financial management policy. Currently some maintenance facilities, such as the Puget Sound Naval Shipyard (PSNS), operate under Defense Business Operating Funds (DBOF) while other facilities, such as the Trident Repair Facility (TRF) and Ship Intermediate Maintenance Activity (SIMA), are mission funded. A financial management policy is needed to simplify and standardize maintenance funding. The second issue deals with resolving key organizational/ownership issues of who owns, who supports, and who controls the fleet maintenance process. The Navy consists of many long standing and powerful "rice bowls" or "stovepipes" which create an atmosphere where everyone is looking out for their own best interest instead of what is best for the Navy. This atmosphere of self-interest and self-preservation needs to be put aside in order to establish a maintenance organization that will meet the Navy's needs into the 21st Century.

3. Phase Three

The final phase of Regional Maintenance builds on Phase Two with fleet maintenance conducted using a single maintenance process supported by a common data foundation between fleets and also supported by common business and production practices. This approach will provide a clear process for ensuring technical authority and oversight by the Systems Commanders. Phase Three is expected to commence no later than FY 97. [Refs. 6,7]

4. Regional Supply Operations

A key feature within the maintenance regions listed above is the integration of maintenance and supply through the Fleet and Industrial Supply Centers (FISCs). This

effort is designed to provide additional streamlining and efficiencies in support of the Regional Maintenance Strategy. FISC operations aggressively target regional management of supply operations to eliminate duplication and layering. Prototype operations in San Diego, California, provided savings of $5M in FY 93 and projected savings of $56M during FY 94-99. [Ref. 6] Significant savings were noted in the areas of inventory, material management, physical distribution, and procurement. Senior Navy leadership anticipates that similar savings will be realized in the other maintenance regions.

F. PACNORWEST PUMP REGIONAL REPAIR CENTER (PRRC)

The PACNORWEST region encompasses the area from San Francisco Bay to the Canadian border, with the majority of installations located in the vicinity of Washington State's Puget Sound. Not all the commands are in close proximity to one another and their missions vary greatly. The PACNORWEST region supports aircraft carriers, aircraft, surface ships, and submarines. This region has the added importance of being the only region in the Pacific theater that has the capability to overhaul and refuel nuclear powered ships.

In November 1993 the Commander-in-Chief, Pacific Fleet (CINCPACFLT) tasked the Pacific Fleet Type Commanders (TYCOMs) to establish process action teams (PATs) to develop the Regional Maintenance Concept. Commander, Naval Air Pacific (COMNAVAIRPAC(N43)) was designated the PACNORWEST RMC PAT leader. The PACNORWEST RMC PAT, renamed the Executive Steering Committee (ESC), began meeting in November 1993 and created seven PATs to explore and examine regional maintenance issues. In March 1994 the ESC formed a

full-time Working Group which provided additional maintenance experience to assist in Regional Maintenance Concept development and to coordinate the efforts of the PATs. [Ref. 8]

The PACNORWEST RMC ESC chartered one PAT to evaluate the industrial capabilities and facilities of the region. Based on the results of a detailed study, the PAT recommended to the Working Group that a Pump Regional Repair Center be established at Puget Sound Naval Shipyard (PSNS), Bremerton, Washington.

PSNS was a logical choice for many reasons. It possesses test facilities for steam driven, hot water, and JP-5 pumps, capabilities not available at other regional sites. Also, PSNS is considered a transportation hub, has ample space and equipment to accomplish the regional workload, has on-site engineering expertise, and has an on-site supply center. [Ref. 9]

On September 6, 1994, PSNS officially opened its doors as the PACNORWEST Pump Regional Repair Center. Phase One's goal of minimizing redundant capability and capacity was accomplished with the PRRC taking on the pump maintenance responsibilities of SIMA Puget Sound, SIMA Everett (not yet completed), Naval Undersea Warfare Center Division Keyport (NUWC Div Keyport), and Trident Repair Facility (TRF) Bangor (TRF continues to perform Trident Planned Equipment Repair (TRIPER) work and refit work).

III. SIMULATION MODELING

A. DISCUSSION

In this chapter the process of simulation modeling is examined and its benefits explained. In addition, the chapter defines and discusses some terms and ideas relevant to the understanding of simulation modeling. Lastly, the importance of selecting the proper probability distribution and proper data gathering is expressed.

B. OVERVIEW OF SIMULATION MODELING

Simulation modeling is a combination of techniques which utilize computers and various statistical techniques to model real world operations. Simulation involves the modeling of a system or process in order to mimic the response of the actual system as the events take place over a period of time. By observing the flow of entities through the model and its outputs, inferences can be made concerning the expected behavior of the system in the future, thereby facilitating the implementation of strategic decisions.

One of the major advantages of simulation modeling is that it facilitates studying the effects of alternative decisions without ever actually operating or incurring the cost of the real system. It provides management the ability to examine "what if" scenarios in order to determine the appropriate strategy. The advantage of being able to take a systems approach is that it considers the interaction of all system components rather than simply concentrating on the individual performance of the parts. Even if each element

or subsystem is optimized from a design or operational point of view, overall performance of the system may be sub-optimal because of the interaction among the individual parts. [Ref. 10] To be effective a total system evaluation is necessary. Examples of pump repair system performance measures that simulation modeling can provide are:

- Throughput - the number of pumps per type repaired per time period;
- Cycle Time - the amount of time it takes to get a pump through the system (turn around time);
- Queue time - the amount of time that jobs are delayed;
- WIP - the size of work-in-process inventories;
- Downtime - percentage of time that a machine is not operating; and
- Utilization - the percentage of time that people and machines are busy.

Through simulation, users can explore how a system will behave if changes are made to the system, or if the inputs are changed. [Ref. 11] Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies for the operation of the system. Simulation allows examination of the effects of change to a system without going to the time and expense of making changes to the real system. With the use of a simulation model as a design tool, answers can be obtained to questions such as:

- What will be the throughput of this new system?

- Will the new system design meet production goals?
- Where are the bottlenecks and what can be done to increase throughput?

C. SIMULATION MODEL DESIGN

The model developed for this research uses the SIMAN simulation language. SIMAN (SIMulation ANalysis) is a simulation language that uses a logical modeling framework to aid in programming. [Ref. 10] It segments problems into two components: the model and the experiment.

The model describes the physical elements of the system in terms of the machines, resources, material flows, and their logical relationships. The experiment specifies the conditions under which the model will run including initial conditions, attributes, resource availability, run length, and the statistics that are to be gathered for the purpose of evaluating the system's performance. Once the model and the experiment have been defined they are linked and the program generates simulated responses of the system. [Ref. 10] The output data can be stored, graphed, used to prepare histograms, confidence intervals, or displayed using presentation-quality graphics packages. [Ref. 10]

The design of a usable decision support model requires a degree of balancing between simplicity and precision. It is necessary to design a model of the real system that neither oversimplifies the system to the point where the model becomes trivial and misleading, nor carries so much detail that it becomes clumsy and expensive. [Refs. 10,11] According to Conway (1987), "the KISS [keep it simple, stupid] principle holds in simulation as it does anywhere

else." Simplicity aids in usability by improving conceptual understanding of the model's function. However, it also requires generalizations be made resulting in some loss of accuracy. However, the model must only behave sufficiently similar to the real system to allow valid conclusions to be drawn. Attempting to go beyond this point by including incidental aspects of the real system that do not materially affect the performance of the system may have undesirable effects. [Ref. 10] In fact, more complex models "are likely to contain undetected bugs that can introduce errors of a much larger magnitude than would be introduced with a simpler model". [Ref. 11]

In an effort to reduce the likelihood of model-induced error and resultant erroneous conclusions on the part of the user, the model developed in this thesis is designed to minimize complexity by combining or eliminating elements that are unlikely to have significant impact on the performance of the system. The primary objective of the model is to demonstrate the relative performance of the system. This simulation model can help predict the behavior of the complex pump maintenance system at the PACNORWEST Pump Regional Repair Center. Simulation accomplishes this by calculating the movement and interaction of system components, evaluating the flow of parts through the machines and workstations, and by examining the conflicting demands for limited resources in the layout.

D. CLASSIFICATION OF SIMULATION MODELS

Simulation models can be classified in several ways. The first distinction among simulation models is whether a model is iconic or symbolic. An example of iconic

simulation models are training simulators such as flight and driving simulators. The main purpose of these types of simulators is to train. Symbolic simulation models, on the other hand, are models in which the properties and characteristics of the real system are captured in mathematical and symbolic form.

Another classification of simulation models relates to the manner in which the model represents and expresses changes of state within the system model. Models can be discrete or continuous. If a model describes changes in the status of the system as occurring only at distinct points in time, it is called a discrete model. A discrete system is one in which the defining variables change only at specific and finite points in time. The PACNORWEST Pump Regional Repair Center is an example of a discrete system because the defining variables change only when a pump arrives for service or departs the system upon completion of maintenance. Continuous models treat change like a ceaseless occurring phenomenon, the variables necessary to define the system at an instant in time change continuously over time. [Ref. 12] An example of a continuous system would be a motorcycle race at Laguna Seca Raceway, because the position, velocity, and acceleration of the motorcycles change continuously with respect to time. [Ref. 13] It is possible to have combination models that represent portions of the system as continuous and portions as discrete.

Models are also classified according to the description of the behavior of the model through time, either being static or dynamic. A model that portrays the behavior of a system at a single point is called a static model.

Spreadsheets and other accounting programs are typical examples of static models. A dynamic model describes the behavior of a system through time, not just at a "snapshot." Most SIMAN models are primarily dynamic. The PACNORWEST Pump Regional Repair Center model is a dynamic simulation model.

The last and most important way to classify models involves its treatment of random variation in the system being modeled. In other words, does the model explicitly incorporate the presence of random variations in the system or not? A deterministic simulation model ignores randomness, assuming it to be unimportant to the decisions that are to be made. However, few real-world systems are free from the effects of random fluctuations. A simulation model that explicitly tries to capture the important random components of a system is called a stochastic model. A stochastic model recognizes that randomness is important and includes random elements in the model design. SIMAN models are primarily stochastic. The PACNORWEST Pump Regional Repair Center model is a stochastic simulation model.

E. PACNORWEST PRRC MODEL SPECIFICATIONS AND ASSUMPTIONS

For this research a symbolic, discrete-event, dynamic, stochastic simulation model is used. Such models are often used for work-in-process (WIP) and material flow problems since they provide the ability to look at the state of the system at selected intervals. [Ref. 10] This type of model is appropriate because of its capability to detect backlog problems which could reduce overall system performance. Additionally the model has the ability to predict the time

required to process a specified amount of material, offering a method to measure and evaluate alternatives and/or determine the system's capabilities. In order to mimic the process of the PACNORWEST Pump Regional Repair Center, the logical flow of pumps must be traced through the model. The execution of the program must follow along without deviation. Therefore, the model can only make decisions that are expressly presented in the logic. Some of the key general assumptions are:

- Tasking of resources is based on user assignment specified at the beginning of a simulation run. Emergent repair work, known as casualty repairs (CASREPs), will alter tasking or sequence without user intervention.
- The default priority rule is lowest-value-first (LVF) for all resources. Immediate access to the next pump to be served is assumed.
- The arrival of a pump on the production line is instantaneously communicated to the first available resource assigned.

F. SELECTING PROBABILISTIC DISTRIBUTIONS

In the Pump Regional Repair Center model, artificial data is generated through the use of a random number generator and specified probability distributions. It is important to be careful when deciding which distributions to choose. Choosing inappropriate probability distributions can adversely affect the usefulness of the simulation results. [Refs. 10,11]

The PACNORWEST Regional Repair Center model uses several types of distributions to represent PRRC operation. The first distribution used in the model represents the generation of pump failures. Pump failures are independent discrete events that occur over an interval of time. Plotting the occurrence of random pump failures occurring in an 18 month fixed time interval results in a distribution that closely resembles the Poisson distribution. Therefore, a Poisson distribution is used to determine the number of pump arrivals to the repair center per 18 month cycle.

The Poisson distribution is an appropriate distribution to use for the arrival of failed pumps, however, it is a poor choice for generating service time. Most service times do not exhibit the high variability associated with the Poisson distribution. [Ref. 10] With less variability in service time one could use the familiar bell curve of the normal distribution, however, the normal distribution assumes symmetric variations both above and below the mean, which is seldom true for service tasks. [Ref. 10] Experience indicates that any given task takes more time than expected far more frequently than it takes less time. A permutation of Murphy's Law exemplifies it best, "any task takes twice as long as it should." [Ref. 13] The effect of this on distribution selection is to indicate a distribution skewed to the right. [Ref. 10]

Pegden, Shannon, and Sandoswki suggest the triangular distribution is useful to introduce variability with limited or absent data. [Ref. 10] The triangular distribution is useful as a first approximation in the absence of data and has simplicity as its primary advantage. It is defined by

three values: a minimum, mode, and maximum. Figure 3 illustrates a triangular distribution.

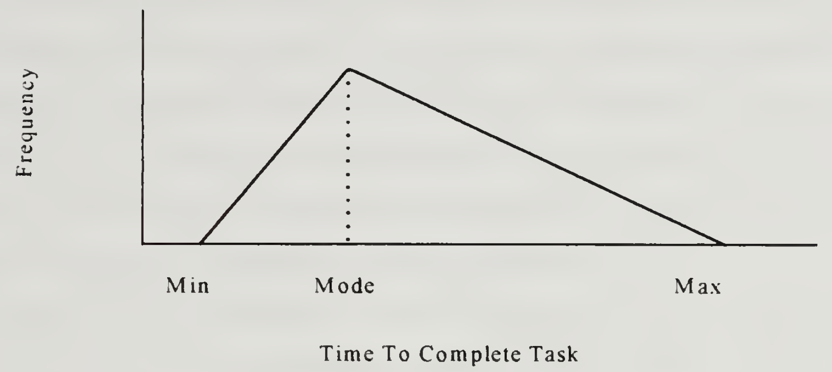

Figure 3. Workstation Service Time Distribution

The density function consists of two segments, one rising from the minimum value to the mode, and the other descending from the mode to the maximum value specified. In addition, the two segments net not be symmetric allowing the distribution to be either skewed left or right as needed. This distribution is most often used when attempting to represent a process for which data is not easily obtained but for which bounds and values can be established based on knowledge of its characteristics. [Ref. 10] The mode is the data value (service time) that occurs most frequently. The service times fall in the interval defined by the minimum and maximum values. In this model a triangular distribution is used to represent the maintenance conducted at each workstation. The calculation of the maintenance time is explained in Chapter IV.

IV. PACNORWEST PRRC SIMULATION MODEL

A. PACNORWEST PUMP REGIONAL REPAIR CENTER

The PACNORWEST Pump Regional Repair Center (PRRC) is the leading pump repair facility in the PACNORWEST region. The PRRC possesses precision machining and balancing capabilities, has an integrated test facility, uses modern repair techniques, provides technical excellence, and offers numerous regional advantages.

Precision machining includes versatile machining capabilities for all pump sizes and types, machining to exact pump standards of accuracy and finish, and vertical, horizontal, and non-traditional machining centers to support pump overhauls.

Precision balancing includes the ability to balance components and assemblies up to 72 inches in diameter, balance to an operational RPM up to 2000 RPM, and provide a guaranteed accuracy to within 1 gm/in.

The integrated test facility is capable of testing lube oil, JP5, and water pumps and components from 1 GPM to 8,000 GPM as well as conducting electric or steam driven component testing. It consists of six stands capable of steaming to 45,000 P.P.H. and a pressurized enclosed loop for hot water testing.

The modern repair techniques used by the PRRC include an efficient and environmentally safe cleaning facility, complete plating and welding services, and the use of epoxy, polymeric, and composite applications and repairs.

Technical excellence is evident with on-site engineering expertise, highly skilled and certified

machinists and technicians, and a workforce capable of handling workload surge. In addition, computerized inspection utilizing coordinate measuring machines for inspection reports is used.

The PRRC, which is located at the Puget Sound Naval Shipyard (PSNS), possesses numerous regional advantages. The PRRC is centrally located in relation to its customers, is a transportation hub allowing for easy access, and has regional on-site Fleet and Industrial Supply Center support for repair parts. [Refs. 14,15]

B. DEVELOPMENT OF THE MODEL

The PRRC model describes the steps that different pump types undergo as they progress through the maintenance process. The pumps are considered the entities in the model. An entity is defined as any object that causes a change in the system as it moves through the system. The service and maintenance times associated with each different type of pump at the various workstations is called the process. A process is the sequential order of operations through which the entities move.

The repair process at the PACNORWEST PRRC is analogous to that of a job shop facility. In a job shop model the workstations are grouped and organized by equipment type and/or similar operations. The jobs flow to each stationary workstation in a sequential order until the maintenance on the pumps is complete.

In the PACNORWEST PRRC model the pumps are routed in a predetermined sequential order through the workstations. Once the maintenance on a pump is complete, it is routed to

the shipping area where it waits for customer pickup. Figure 4 is a block diagram of the PACNORWEST PRRC process.

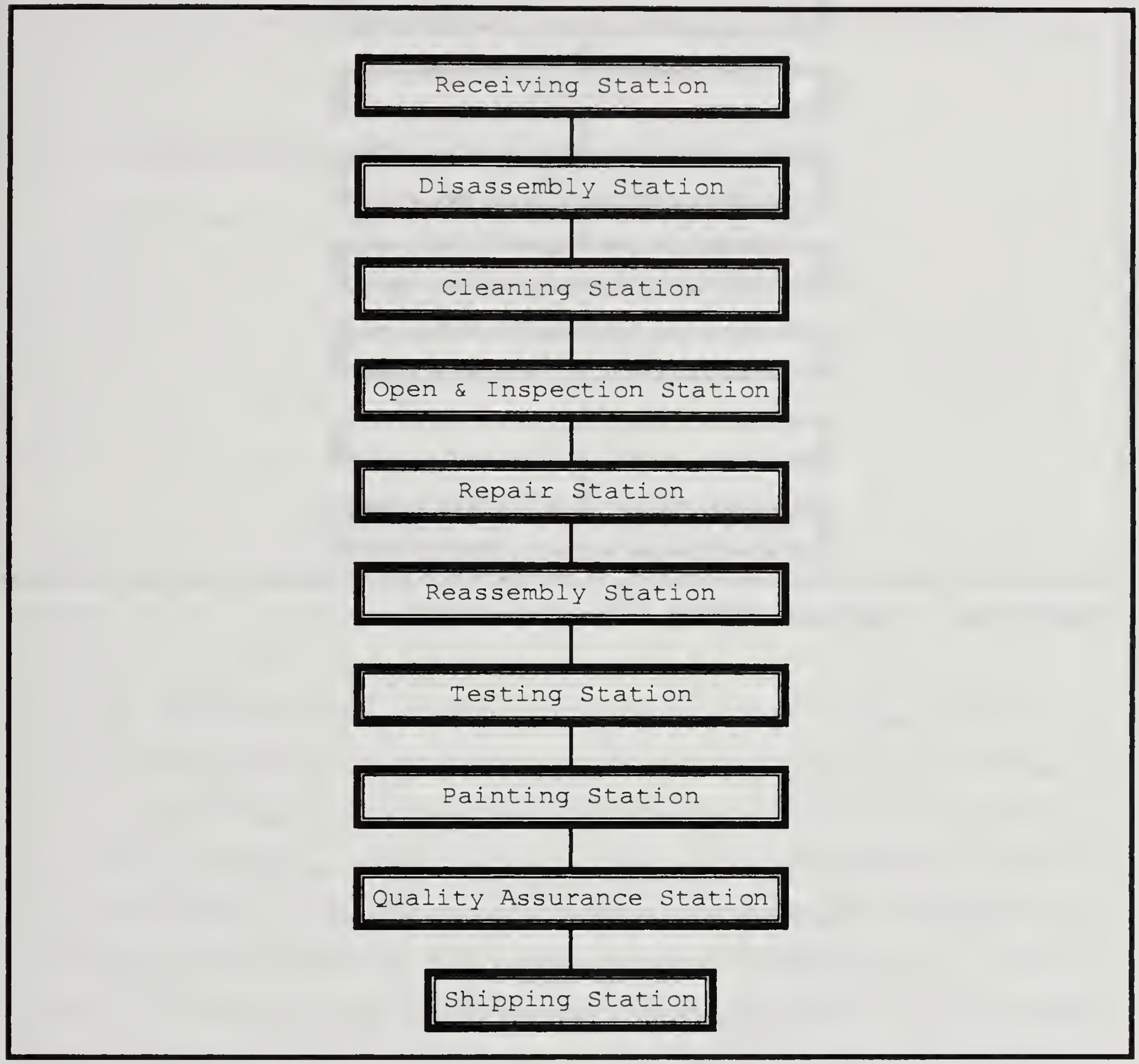

Figure 4. PACNORWEST PRRC Process Flow by Workstation

Figure 5 illustrates the typical movement of a pump through a SIMAN submodel block. A submodel represents a workstation. Each pump type in the PACNORWEST PRRC model undergoes the same process through each submodel.

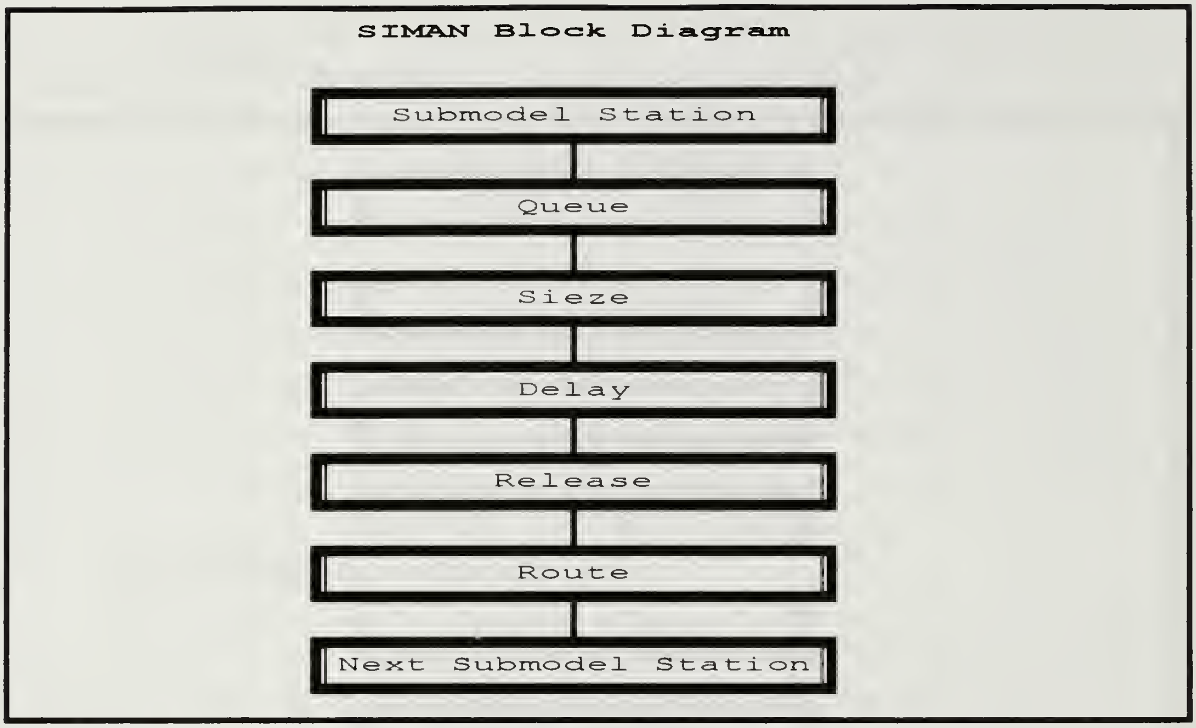

Figure 5. Typical SIMAN Submodel Block

When a pump arrives at the PRRC it is evaluated by the planning and evaluation (P&E) personnel at the receiving workstation. The receiving workstation is the first submodel station in the simulation. When a pump arrives at the receiving submodel workstation it waits in the queue until it is evaluated and transferred to the next submodel workstation, the disassembling workstation. At the disassembling workstation the pump waits in the queue and is seized by the first available resource (maintenance personnel). Once seized the pump begins its maintenance cycle through the submodel workstation. Each pump type is delayed at the submodel workstation according to its designated service time. When the maintenance (delay) is complete the pump is released to the route block were it is then transferred to the next sequential submodel

workstation. The pumps continue this sequential flow through the submodel stations loop until the visitation sequence and maintenance is completed. Once completed the pump departs the system.

C. LIMITATIONS AND PARAMETERS OF THE MODEL

Because of the relatively short period of time the PRRC has been operational, limited production data and logistical data exists. Several assumptions had to be made in order to simplify and facilitate the development of the PACNORWEST PRRC model. These assumptions limit the direct comparison to the real world PRRC.

The most important of these assumptions is that the model does not take into account logistic and administrative delay time. A queue of unrepaired pumps awaiting logistic support in order to complete repair is not serviced any faster if there are more repair facilities to service them. [Ref. 13] Therefore, awaiting parts, shipping lead time, and administrative delays are not factors in this model.

To determine the arrival rate of the pumps to the repair center, assumptions also had to be made concerning the mean time between failures (MTBF) of the pumps. The MTBF of the different pump categories was derived from the projected workload and availability analysis conducted by the Workload PAT. [Ref. 16] Additionally, there was only limited data available relating to the maintenance time at each substation. Data were obtained from PRRC personnel based on limited observation and educated guesses by experienced repair maintenance personnel.

The design and intention of the PRRC simulation is to test the feasibility and capacity of a consolidated

maintenance facility. The simulation model shows that the PACNORWEST PRRC can provide maintenance to the maximum number of pump arrivals in a given period without having pumps accumulate in a significant queue. In addition, the model can express the average pump turn around time (TAT) to facilitate the determination of the promised delivery date (PDD) to improve customer satisfaction and fleet readiness.

Next, PRRC resource allocation, the number of ships in the PACNORWEST Region, PRRC pump arrival rate, and PRRC workstation mean service time are discussed in order to construct the PRRC simulation model.

1. PRRC Resource Allocation

The PACNORWEST PRRC mode of operation consists of one eight hour shift with no duty section work. Overtime is granted on a case-by-case basis depending on the workload. Currently considerations are being made concerning the addition of another shift once total phase implementation has been accomplished. The PRRC allocates 40 operating hours per labor week for a total of 160 operating hours per labor month. For the purpose of this model there was no allocation of overtime and 160 hours represents the length of a calendar month.

There is a total of thirty-two workers at the PRRC of which nineteen are mechanics, four are support personnel, and nine are overhead, e.g., management, engineering, and administrative personnel. Combining maintenance hours for the PRRC gives a total of 3680 labor hours available for maintenance per month. However, this maintenance hour estimation assumes that a worker is actively conducting maintenance work eight hours a day. This estimation does

not take into account the time taken for lunch, coffee breaks, meetings, training, physical readiness test (PRT), sickness, leave/vacation, and other circumstances not associated with direct maintenance time. It is unrealistic to expect a full eight hour maintenance day, therefore, a labor utilization factor is applied to the maintenance day. Another factor affecting direct maintenance time is the existence of two labor forces, military and civilian. It is estimated that the military labor force has a labor utilization factor of 0.7 and their civilian counterparts have a 0.8 labor utilization factor. [Ref. 15] The PRRC model makes no distinction between military and civilian personnel so a 0.78 labor utilization factor, the weighted average of the estimated labor utilization factors is used. Using this labor utilization factor, the total expected maintenance hours for a month is 2870. A full eight hour workday is now estimated to provide six hours and twenty-four minutes of direct maintenance time.

To simulate the flow of pumps through the system it is necessary to determine the number of resources available to perform maintenance at each workstation. A resource is equal to a two-person team. The PRRC has enough direct maintenance personnel to form nine two-person teams. These two-person teams are assigned to a pump at the receiving workstation and shadow the pump until it departs the system. Therefore, all submodel stations are limited in capacity by labor-hours not equipment with the exception of the operational testing (OPTEST) substation. The OPTEST substation is limited by both labor-hours and equipment. Only one pump can be processed at the OPTEST substation at a time and as a result only one resource channel is available.

2. Number of Ships in the PACNORWEST Region

The PACNORWEST is a growing region. Currently the Navy has plans to move two Nimitz Class aircraft carriers (USS Abraham Lincoln and USS Carl Vinson), two Kidd Class guided missile destroyers (DDGs), and two Spruance Class destroyers (DDs) to the region. In addition, the newly commissioned Supply Class auxiliary ships are to be homeported in the PACNORWEST. The arrival of more Oliver Hazard Perry Class guided missile frigates (FFGs) is still being considered. These projections are summarized graphically in Figure 6.

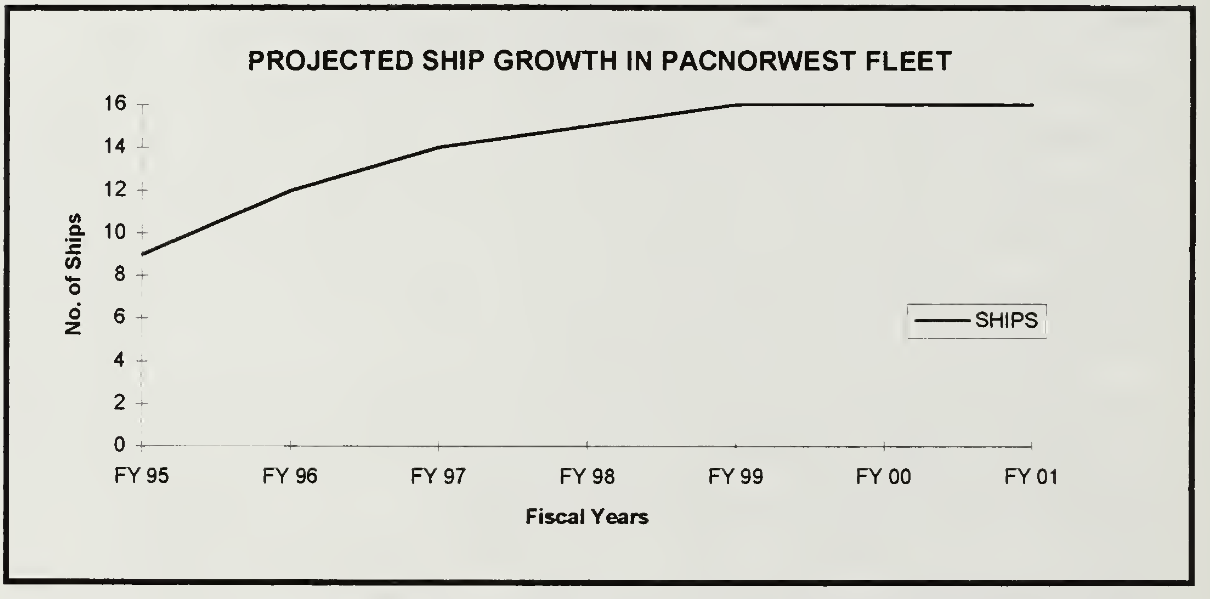

Figure 6. Projected Ship Increase in the PACNORWEST Region

3. PRRC Pump Arrival Rate

In order to mimic the operations of the PRRC, the arrival rate of faulty pumps to the pump repair center was determined. Pump failures are described as discrete independent events that occur over a defined time interval. In this model the time interval is set to eighteen months

which is equal to the time between scheduled ship maintenance periods.

The types of ship maintenance considered were Selected Restricted Availability (SRA) and Dry-dock Selected Restricted Availability (DSRA). Figure 7 graphically represents the forecasted workload by pump type.

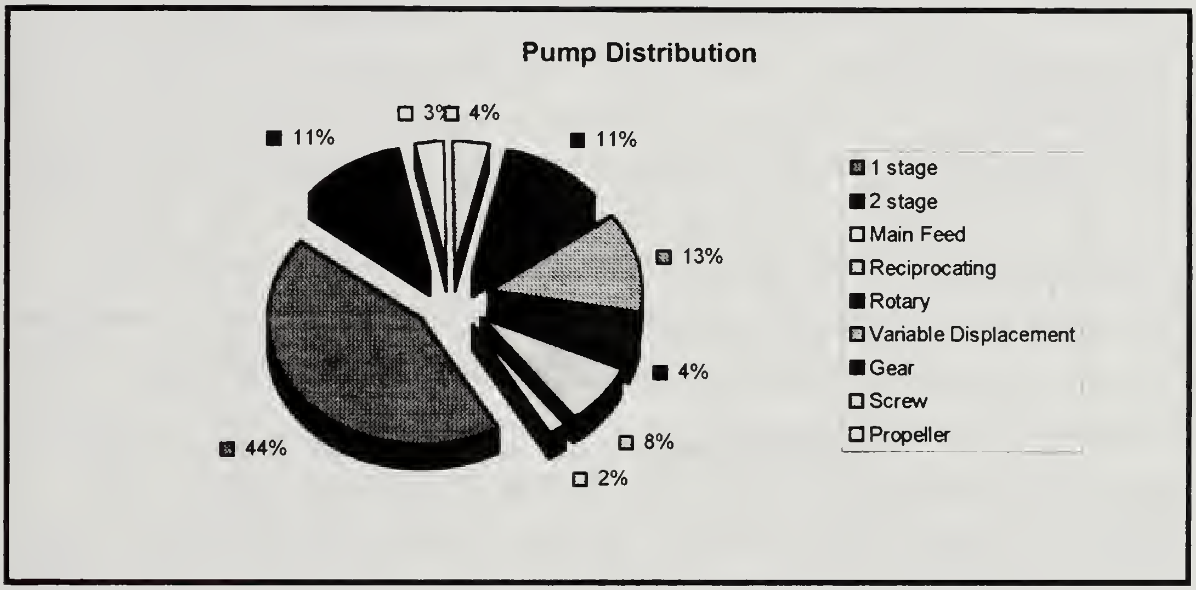

Figure 7. Pump Type Distribution

As previously stated in Chapter III, the best probability distribution to represent the arrival of faulty pumps is the Poisson distribution. Plotting the occurrence of the number of random failures against the fixed time interval in which they occur results in a distribution pattern that closely matches the Poisson distribution. A Poisson distribution is used to describe the number of events that occur in an interval of time when the events occur independently, such as the number of pump arrivals to

the repair center. The mean of the Poisson distribution is lambda (λ) which is the failure rate. The mean time between failure (MTBF) is the reciprocal of the failure rate ($\mu = 1/\lambda$).

The MTBF of the surface ship pumps serviced at the PACNORWEST PRRC was not readily available. Based on this circumstance, assumptions had to be made in order to derive a MTBF. Data was gathered from the PACNORWEST Regional Maintenance Report. [Ref. 17] In this report the PAT responsible for workload forecasting gathered data and derived a forecasted workload for the PACNORWEST Region from FY 95 to FY 2003. The PAT's workload forecast was based on the scheduled availability of ships, projected workload derived from estimated failure rates, forty percent emergent work, and budget constraints. The budget constraints limited the work scheduling based on the anticipated funding for the particular ship's maintenance availability. The period between maintenance availabilities is equal to the operational time of each ship.

In order to determine the MTBF of the different pump types, the failure rate for each pump type was derived. By definition the failure rate is the number of failures divided by the operational time of the component. The total number of pump failures per ship was calculated by adding all the forecasted workload, by availability and pump type and then multiplying by the number of ships in each class stationed in the PACNORWEST region.

The operational time of the ships was established and calculated to be eighteen months, however, a ship is not

operational for this entire period. For the purpose of this thesis an operational ship is define as one which is operating under its own power, not being supported by pier services, e.g., steam, electricity, and waste disposal. Thus, a ship that is pierside and using pier services is not considered operational. To define operational time, the model uses a sixty-five percent operating tempo based on data collected by the CNO's office. In other words, a ship with an eighteen month period between maintenance availabilities is operational for 11.7 months. Using this operational time and the forecasted number of pump failures, the failure rate (λ) of each type of pump was derived.

The next step was to determine the MTBF of each class of pump. Having already determined λ for each class of pump, the MTBF for all pump types was calculated.

4. PRRC Workstation Mean Service Time

The characteristics of the submodel workstation service time does not follow that of the pump failure rate nor does the time distribution resemble the Poisson distribution. Due to the lack of data relating to the individual service times per workstation per pump type, the triangular distribution is used to represent the service time based on its estimatability. The only service time data available was the average maintenance service time observed by maintenance personnel for all the pumps serviced at the PRRC from October 1994 to March 1995. No distinction was made among pump types. In addition, estimated average service times at each workstation were obtained from maintenance personnel based on their experience. The mode of the triangular distribution at each workstation was set equal to

the estimated average service time at each workstation. Based on the premise that any given task takes more time to perform than expected far more frequently than it takes less time. The experience of PRRC personnel lends credence to a triangular distribution with a minimum value of 90% of the mode and a maximum value of 120% of the mode. [Ref. 15] These two values allow for the skewing to the right of the distribution which supports what empirical maintenance experience suggests for service time. [Ref. 10] The model and the experiment are illustrated in Appendix A.

D. VERIFICATION AND VALIDATION

The fact that the model compiles, executes, and produces numbers does not guarantee that the results are correct or that the numbers being generated are representative of the system being modeled. The process of determining the correctness of the model consists of two different functions: verification and validation. Verification is the process of determining that a model operates as intended. Validation is the process of reaching an acceptable level of confidence that the model is producing relevant information pertaining to the real system. [Ref. 10]

1. Verification of the Model Using Test Runs

One method of verifying a model is through the use of test runs which facilitate the detection of errors in the logic by breaking the model into smaller components. This allows for quick and easy debugging of errors. In the test runs, random times are replaced with constant times in order to reduce variability. [Ref. 10]

In addition to test runs, the model can also be executed under extreme worst-case scenarios. To verify the PACNORWEST PRRC model the simulation was run at very high and very low arrival rates.

In order to create a "congestion" within the model and to verify that the model can withstand stress situations, the pump arrival rate was increased and the service time at the substations was increased. Figure 8 shows the model responds appropriately creating "congestion" and longer TAT for the pumps.

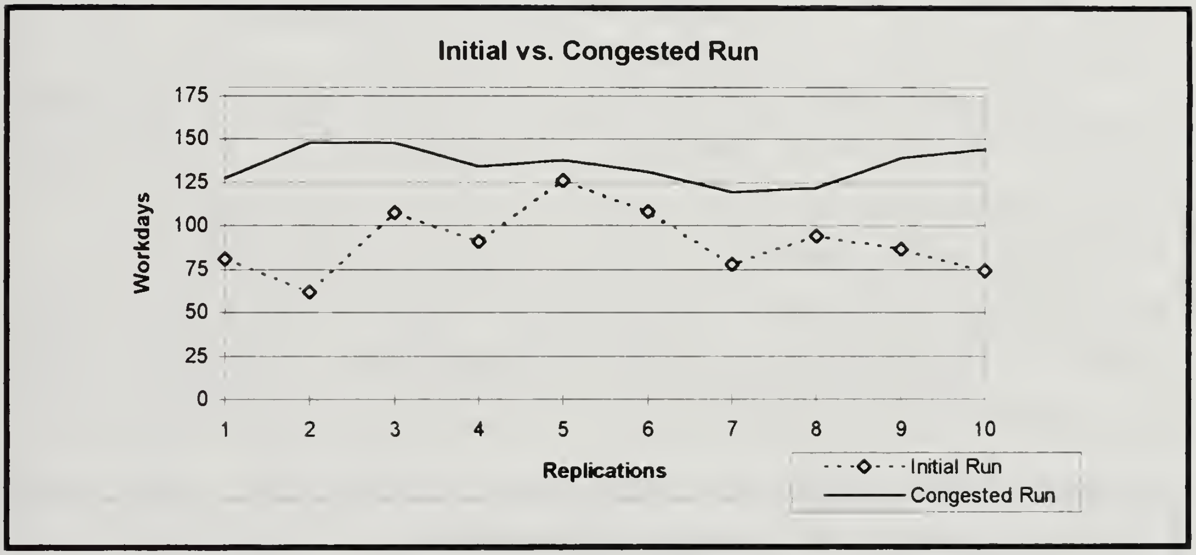

Figure 8. TAT in the Initial and Congested State

Additionally, Figure 9 illustrates how the number of pumps in the queue awaiting maintenance significantly increased in a "congested" condition. Thereby, further verifying the model.

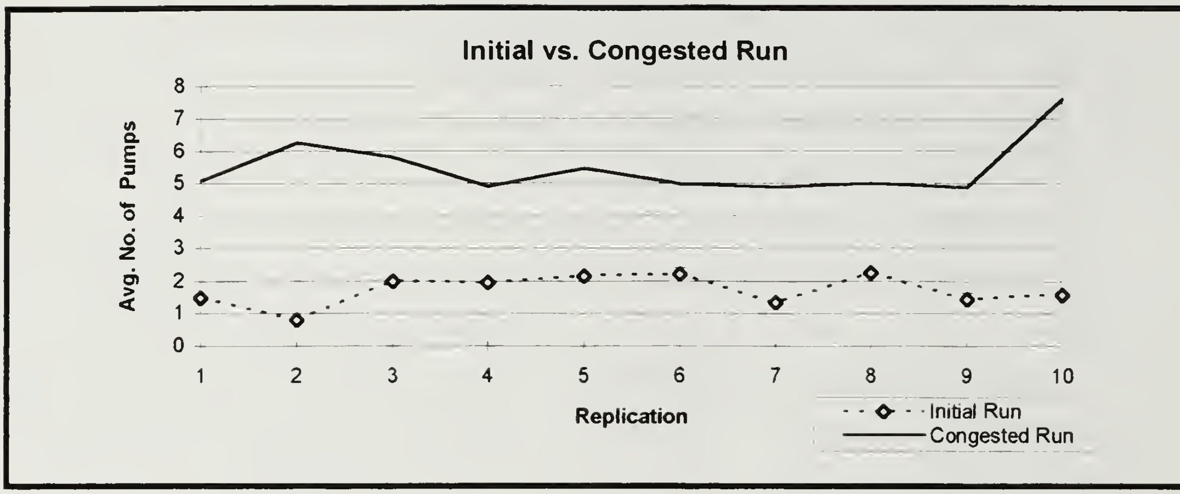

Figure 9. Queue Length in the Initial and Congested State

Next, the opposite approach was also tested. To verify that the model would operate in a condition of "starvation" the failure rate was reduced and the service times at the workstations decreased. Again the model responded accordingly drastically reducing the TAT of the pumps and reducing the queue size at the workstation. Figures 10 and 11 illustrate the "starvation" conditions in the model.

Figure 10. TAT in the Initial and Starvation State

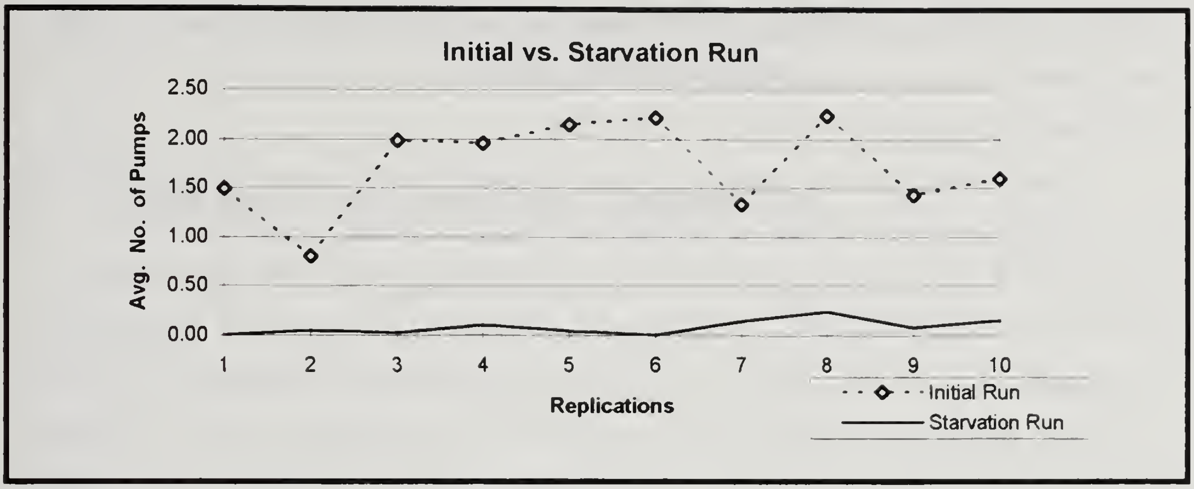

Figure 11. Queue Length in the Initial and Starvation State

2. Validation of the PRRC Model

Validation techniques are intended to demonstrate that the model is adequately representing real world operations. [Ref. 10]

Ten replications of the model were run for 4380 time units, each time unit represents a day. Thus, the PRRC model simulated an eight year period. To allow for phase implementation of the Regional Maintenance Concept adjustments and setup time, a warm-up period was included in the model. The warm-up period was equivalent to 18 months.

The outputs produced by the simulation model include average, maximum, and minimum pump turn around times, the average number of pumps in the queue, and the average labor utilization at each workstation. Appendix B contains the output of the model.

The simulation output indicated that there was not a significant number of pumps awaiting repairs in the queue and no labor utilization factors were above 50 percent.

There was insufficient historical data available to validate this model. Only verbal validation could be

obtained. The output of the model was discussed with PRRC management personnel and was found to be consistent with the real world operations at the PRRC.

The simulation results are essentially estimates which are based on the best available data. With additional quantification of pump arrival rates and workstation mean service times, further validation of the model is possible. In order for this model to be completely validated, its outputs must be compared to actual operational data of the PRRC.

V. PRACTICAL APPLICATIONS AND EMBELLISHMENTS OF THE PRRC MODEL

A. SIMULATION AS A DECISION SUPPORT TOOL

One of the major benefits of simulation is the ability to conduct "what if" scenarios without incurring the cost of making permanent changes to the actual process. Management can evaluate different scenarios under various conditions (e.g., add workers and/or machines, extend working hours, or introduce other variables) until they are satisfied with the results of the model, then apply these changes to the real operations.

For example, if the model discloses a large backlog at the testing workstation, the manager can experiment to see what mix of resources will obtain the desired result, smaller queue length. In this case the manager may find that adding another two-person team to the workstation has a greater effect on reducing queue length then adding an additional test stand.

Along the lines of this example, reduced queue lengths lead to reduced TATs. This information is very useful to P&E personnel in determining a more accurate promised delivery date to the customer, thereby improving customer service. A more accurate promised delivery date enables the Commanding Officer of a ship to maintain the training and readiness of his or her crew by making their underway commitments.

The authors evaluated the PRRC model by examining the relationship between TAT and queue length and then introduced several changes in resources available to the

PRRC in order to see how the repair center would be effected. This relationship and model embellishments are described below.

B. RELATIONSHIPS AND MODEL EMBELLISHMENTS

1. Queue Length and TAT Relationship

The PRRC model demonstrates how the average number of pumps in the queue directly contributes to the fluctuation in the average TAT of the pumps. Figure 12 illustrates how the average TAT of single stage pump increases as the number of pumps in the queue increases. However, the fluctuations in the number of pumps in the queue slightly lag behind the average TAT. This is due to the existence of other pumps in the process awaiting repairs.

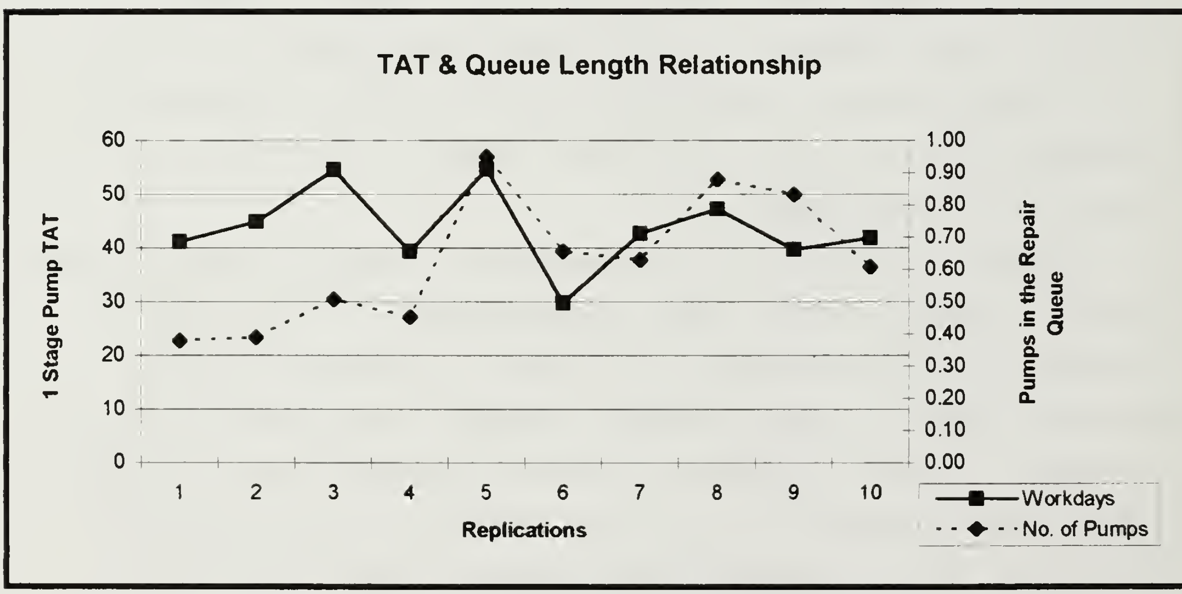

Figure 12. TAT and Queue Length Relationship

2. Number of Pumps in the Queue

The first embellishment deals with examining the number of pumps in the queue awaiting repair maintenance. Figure 13 shows the simulation output for queue length. This information is essential to the shop manager in order to identify the location and size of backlogs in the repair operation. One of the primary jobs of a manager is to identify backlogs and then take appropriate actions to reduce or eliminate them. Figure 13 shows the largest backlog at the repair workstation.

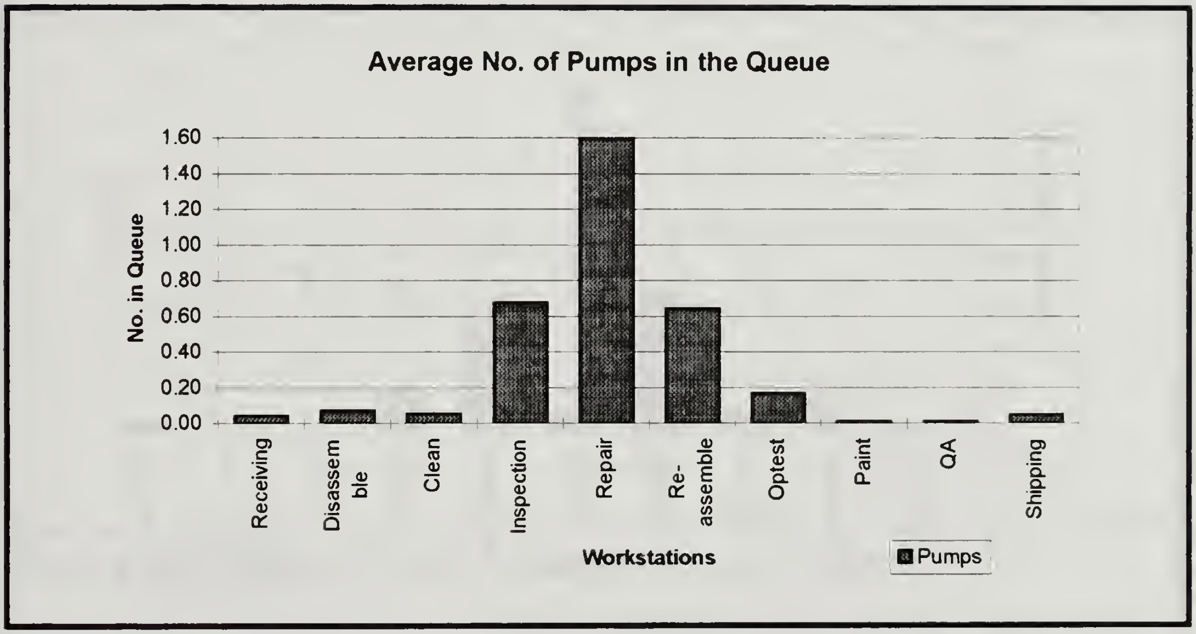

Figure 13. Average Number of Pumps in the Queue

The PRRC manager should examine the repair station to see if additional qualified personnel or a physical modification to the repair workstation facility can reduce the queue length. The authors decided to add an additional two-person team (additional resources) to the repair workstation and examine the results. Figure 14 reveals a

reduction in queue time at the repair workstation. The largest queue in the process is now located at the inspection workstation. A manager can continue to create "what if" scenarios to determine the best process that satisfies the requirements of the operation. However, consideration must be made concerning the additional costs incurred when modifying the operation. A tradeoff analysis must be made as to the marginal gains obtained in the process by adding one more resource. The cost of additional resources was not explored in this thesis.

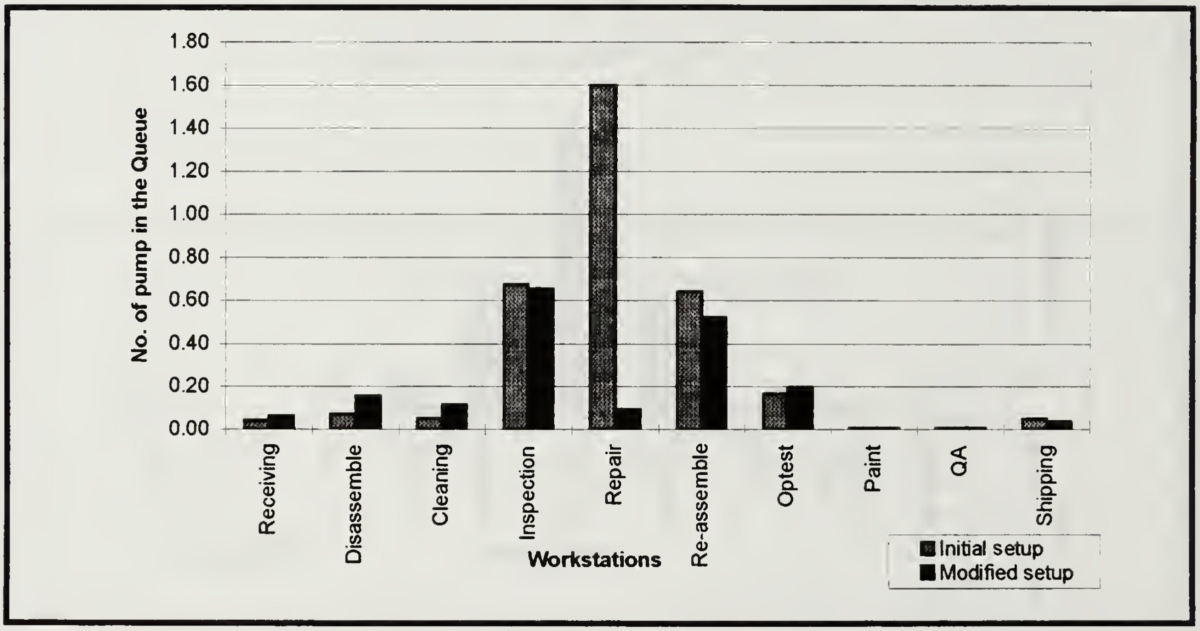

Figure 14. Queue Reduction Analysis

3. Pump Turn Around Time

The second embellishment examines the TAT. By identifying the average and minimum TATs of pumps in the repair process, Planning and Estimation (P&E) personnel can increase the accuracy of the promised delivery date (PDD).

If P&E personnel are consistently underestimating or overestimating the PDD, the data shown in Figure 15 can be used to refine their estimates and improve customer service by reducing the variability of the PDD.

PRRC management should continue to reduce the difference between the average TAT and the minimum TAT. By continuously improving the process and reducing the delta between the two TATs, PDD can be estimated with greater confidence.

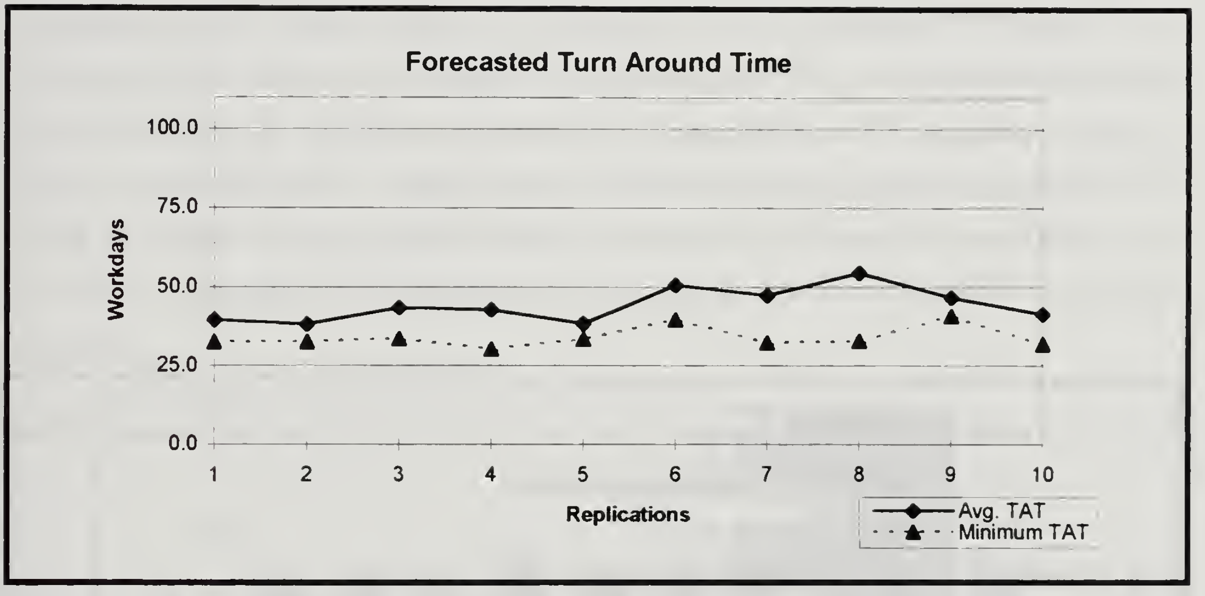

Figure 15. Average and Minimum Pump TAT Comparison

4. Turn Around Time and its Implication on Readiness

TAT is one of the most important factors that effect the readiness of the fleet. This embellishment explores TAT from a different perspective. The TAT of a pump being repaired is extremely important when examined from the viewpoint that without certain types of pumps a ship may be unable to get underway and perform its mission, thereby,

reducing fleet readiness. Any ship CO when asked when he or she needs a pump back will invariably answer, "Yesterday!" The simulation model allows the shop manager to view current TATs and see how additional resources can reduce TATs and provide the customer with what they desire: rapid maintenance response.

Figure 16 compares the original pump repair center setup to a modified setup with additional resources. As illustrated in Figure 16, the addition of another two-person team to the repair workstation has reduced the TAT of all the pumps. However, the reduction of the TAT of the pumps has come about with the additional cost incurred by the added resource. Here again tradeoffs have to be made to determine an acceptable level of customer satisfaction. Is the additional cost of two more employees worth getting the pumps to the customer a week earlier than estimated?

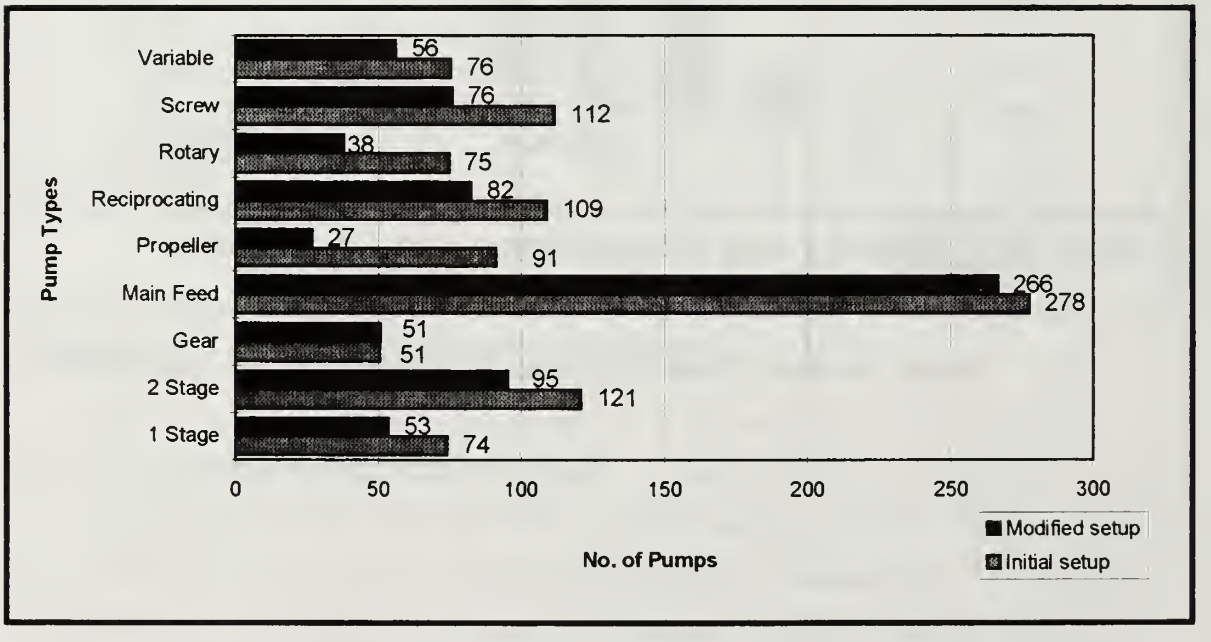

Figure 16. TAT Comparison with Additional Resources

5. Rework and Turn Around Time Implications

It is important to note that the addition of resources does not necessarily increase the throughput of pumps at the PRRC, as illustrated in Figure 17. The number of rework jobs that have to be re-processed have a greater effect on the increase or decrease in throughput at the PRRC than the addition of a two-person team. If pumps continue to arrive at the PRRC at the same rate, an increase in resources will probably have a greater effect in decreasing the TAT of the pumps, thereby, making more time available for catch-up work or long lead time items. However, if a pump fails the operational test, the pump is sent back to the disassembling workstation, thereby, adding another pump to the awaiting maintenance queue. The importance of this comparison is that while the addition of a resource can reduce the TAT of a pump, it does not directly increase the throughput in the system.

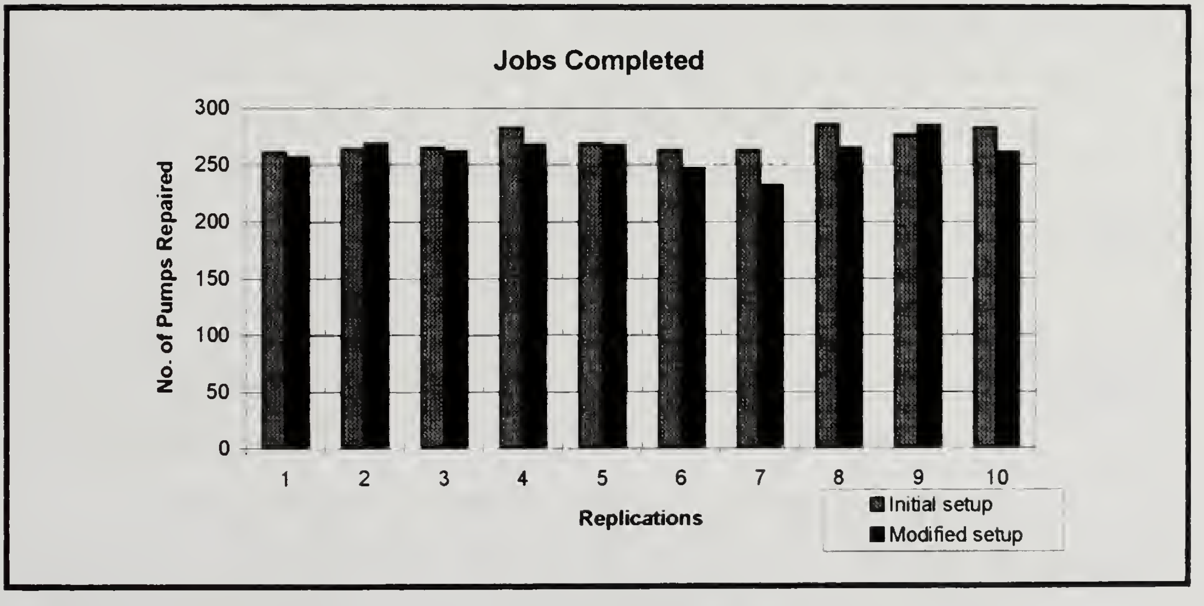

Figure 17. Predicted Total Jobs Completed

VI. MEASURES OF EFFECTIVENESS

A. DISCUSSION

The PRRC simulation model discussed in Chapter IV provides useful information to assist managers in the decision making process to allocate limited resources. The model can be used to predict turn around time (TAT) for different pump types, utilization rates of maintenance personnel at each workstation, and the number of pumps in the queue awaiting repair. While this information is essential to the managers it lacks one very important aspect, effectiveness. What is an effective PRRC?

This chapter examines the concept of effectiveness in the context of the PRRC and proposes a measure of effectiveness (MOE) for the PRRC.

B. WHAT IS EFFECTIVENESS?

Effectiveness has been defined as "the degree to which the intended public purpose of a service or activity are being met." [Ref. 18] It is often difficult to get a consensus on what "effectiveness" means because its definition is so context dependent. In Webster's dictionary the words "efficient" and "productive" are listed as synonyms for the word "effective." This has resulted in effectiveness being confused with words such as efficiency, performance, and productivity by imprecise users.

In this thesis, effectiveness is not necessarily related to efficiency and productivity. A highly efficient organization may be an ineffective one. For example, a company that makes record players with a minimum number of

workers and a small amount of resources, demonstrating high efficiency, may not be very effective at meeting the music listening needs of today's customers. Not as many customers desire record players as want compact disc players. On the other hand, an effective organization may be inefficient. For example, a philanthropic organization might regularly deliver clothing to poor families in a community, but if it is paying Federal Express to make the deliveries when a volunteer worker with a truck might do equally as well for no pay, it could improve its efficiency.

Effectiveness, in the context of the PRRC, is directly related to timeliness. The Commanding Officer (CO), whose ship can not get underway until its main feed pump is repaired and installed, is very aware of the promised delivery date (PDD) determined by the PRRC. To the CO, an effective PRRC is one that repairs the main feed pump on or before the PDD.

C. THE PURPOSE OF THE PRRC

Before appropriate measures and units can be selected to measure effectiveness, the struggle over defining the purpose of a activity must be resolved. The private sector has a readily accepted measure of effectiveness: profit. However, government agencies and activities have a more difficult time measuring effectiveness because they do not produce goods or services that are exchanged in the competitive marketplace. They have no clearly defined and widely accepted measure of output such as the net profit of a company. [Ref. 19]

The service provided by the PRRC is pump maintenance support for ships and submarines (the customers) of the Pacific Northwest. Because maintenance is the service provided to the customer by the PRRC, it is appropriate to include the customer in the definition of the effectiveness of the PRRC. What does the activity receiving maintenance want? The customer wants high quality work in a timely manner within budget. That is, an effective PRRC is one that demonstrates the ability to perform work quickly and properly while staying within budget.

Measuring the quality or cost of repair work are not the subject of this thesis. However, an attempt to define a measure of effectiveness that captures the essence of PRRC effectiveness in the context of timeliness is provided.

D. RELEVANT TIME INTERVAL

Two different time intervals were considered to represent the effectiveness of a PRRC.

The first time interval considered starts when a job is placed on a ship's worklist and ends when the repaired pump is reinstalled onboard the ship. The smaller the time interval for a pump, the more effective the PRRC is in performing the repair maintenance. This time interval is not a satisfactory measure of PRRC effectiveness because there are too many variables outside the direct control of the PRRC. The PRRC only has control over the time it takes to repair the pump. This time interval also considers the time it takes to rig the pump on and off the ship as well as the transportation and logistics time between the ship and the PRRC.

The second time interval is a refinement of the first. It consists of the time when the pump arrives at the PRRC receiving area to the time the pump is repaired and is awaiting pick-up at the PRRC shipping area. In this case, the effectiveness of the PRRC is determined by how well the PRRC personnel manage elements under their control to meet their customers' needs. The notion of customer's needs can be captured in the customer's required delivery date (RDD). Shipboard personnel usually determine when they need a pump returned based on when the ship must get underway. A ship usually wants the repaired pump installed and tested prior to getting underway. In this manner the PRRC is effective when it returns a properly repaired pump to the customer on or before the customer's RDD.

E. PRRC MEASURES OF EFFECTIVENESS (MOE)

It is first necessary to select the group of pumps to be used to calculate a measure of effectiveness (MOE). The group can be all pumps completed by the PRRC in any given time period, for example, a quarter or a year. Next determine the "delta" for each maintenance job where

Delta (Δ) = Estimated Completion Time (ECT) - Actual Completion Time (ACT)

The measures of effectiveness are

T_p = number of days that p percent of work requests in the group considered have $\Delta \leq T_p$, and

P_t = percent of maintenance jobs in the group considered that have $\Delta \leq t$. [Ref. 19]

The measures of effectiveness are related to each other in the following manner:

$$P\left(T_x\right) = x, \text{ and}$$

$$T\left(P_x\right) = x. \text{ [Ref. 19]}$$

For example, consider $P_{30} = 50$. It follows from the above definition that $T_{50} = 30$. In other words, the percentage of jobs completed in 30 days or less, P_{30}, is 50 percent. Likewise, the number of days required to complete 50 percent of the maintenance jobs, T_{50}, is 30 days. Defining both P_t and T_p gives the user flexibility to emphasize the percentage of work completed in a given time *t* or how long it takes to complete a given percentage of work *p*.

These MOEs are designed to be used by PRRC managers and P&E personnel to improve customer satisfaction. For example, a ship has a required delivery date (RDD) of 14 days for a particular pump. Using these MOEs the PRRC manager could be able to tell the ship that based on historical data only 25 percent of the time has that pump type been repaired in 14 days or less. This provides the customer with a realistic expectation of getting the pump repaired by the RDD. The PRRC manager can then provide a more reasonable promised delivery date (PDD), such as 21 days where 90 percent of the time the pump type has been repaired in 21 days or less. This allows for better communication of capabilities between the repair center and the customer, thus improving customer service.

F. CONCERNS WITH THE PRRC'S MOE

As with any measure of effectiveness there are good and bad points.

A good point is that these MOEs capture the essence of timely response to customer pump repair maintenance needs. It measures how long the customer or ship is waiting to have the maintenance performed.

A bad point is that even though these MOEs are based on activities that occur within the PRRC there are still several factors that the PRRC has little control over. For example, the length of time the PRRC takes to repair a pump can be extended by waiting for repair parts from the FISC (logistics delay) and by letting contracts to civilian companies or other repair centers for pump motor repair.

It is important to realize that these delays of maintenance are an understood part of the time interval "delta." A MOE is designed to capture enough of the trait of interest to be useful in monitoring performance and identifying potential process improvements. These MOEs should be used by managers to identify departure from the acceptable norm and to indicate areas for performance improvement. [Ref. 19]

In today's competitive environment, results are what matter. The proper time to address efficiency and productivity is after effectiveness has been determined. Only after it has been determined that the PRRC is accomplishing its intended mission, is it worthwhile to work on improving efficiency and productivity.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. DISCUSSION

In the current environment of decreasing defense dollars, the Navy is actively searching for ways "to do more with less." One of the Navy's major initiatives to save money and become more efficient is to examine its industrial base. This thesis examines the repair operations at the PACNORWEST Pump Regional Repair Center (PRRC) at Puget Sound Naval Shipyard, Bremerton, Washington. The focus of this thesis is to develop a simulation model and a measure of effectiveness (MOE) for the PRRC. The model and MOE are designed to be used as tools to assist PRRC managers in evaluating the pump repair process and determining PRRC effectiveness.

B. CONCLUSIONS

Using the SIMAN simulation modeling software, a simulation model of the PACNORWEST PRRC was developed with the results illustrated in Appendix B. Utilizing the Workload Process Action Team's pump workload forecast through FY 2003, the model produced the average TAT, average queue length, and average worker utilization with a confidence level of 95 percent. Based on the model's average pump TAT, an estimated average capacity of 252 pumps (consisting of nine different pump types) can be processed at the PRRC without causing significant backlogs at the workstations. However, this number of pumps is not an indication of the actual capacity of the PRRC, but rather an estimate derived from the model.

Further, the model indicates that an insignificant number of pumps should become backlogged in the awaiting maintenance queues. In other words, pumps should not wait needlessly in the queue for repair. These small queues lead to shorter pump TATs, thereby reducing ship downtime and improving fleet readiness.

Although additional model validation is needed, the PRRC model sufficiently replicates the real world operations at the PRRC to illustrate the usefulness of simulation as a management tool for planning purposes. More accurate results can be obtained by updating the model through the aggressive gathering and recording of data pertaining to the arrival rates of the different pumps types and the service times at each workstation. Nonetheless, the model constructed for this thesis provides a strong indication that the PRRC can fulfill all surface Navy requirements in the PACNORWEST region.

Using the PRRC simulation model to predict the future utilizing past data is useful, but the greatest benefit of the model is that it allows a manager to evaluate his or her process by providing probability distributions of key measures of effectiveness. With the current resources at hand, the manager can run the model and predict the average, minimum, and maximum TAT for pump repair. The simulation output produces a probability distribution similar to the one shown in Figure 18. This figure illustrates the average turn around time for the repair of a particular pump type.

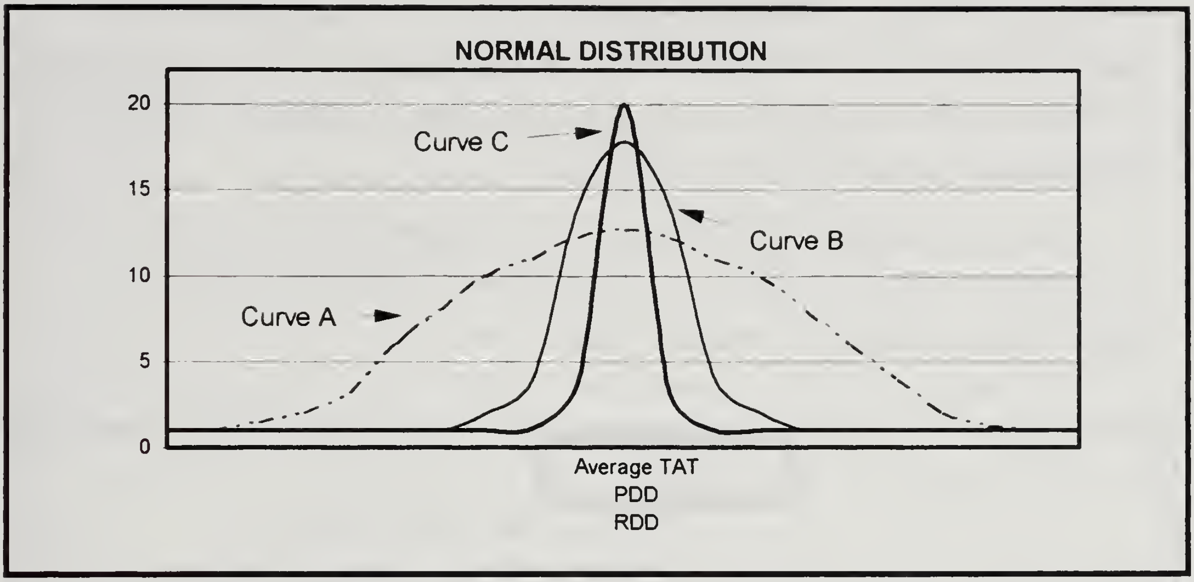

Figure 18. Simulation Output as a Probability Distribution

Armed with this TAT probability distribution, the manager can take two different courses of action that will lead to improved customer satisfaction.

First, the manager can reallocate the PRRC's resources, e.g., add a two-person team to the repair workstation, in order to reduce queue length, thereby reducing overall TAT. The reduced TAT provides the customer with the rapid repair maintenance they desire.

Second, the manager can take appropriate actions to reduce variability in the pump arrival rate and mean service time, e.g., installing a bar coding system at each workstation to monitor pump arrivals and repair start and stop times. The reduced variability in the model's input will result in less variability (more confidence) in the TAT. This is shown graphically in Figure 18 as movement from Curve A to Curve B to Curve C. The manager's goal is to continuously reduce the variability in TAT to the point

that the average TAT, promised delivery date (PDD), and required delivery date (RDD) are the same. A more accurate promised delivery date will provide the customer with the high quality service they demand.

The previously discussed relationship between the simulation model and how it effects customer satisfaction is shown graphically in Figure 19.

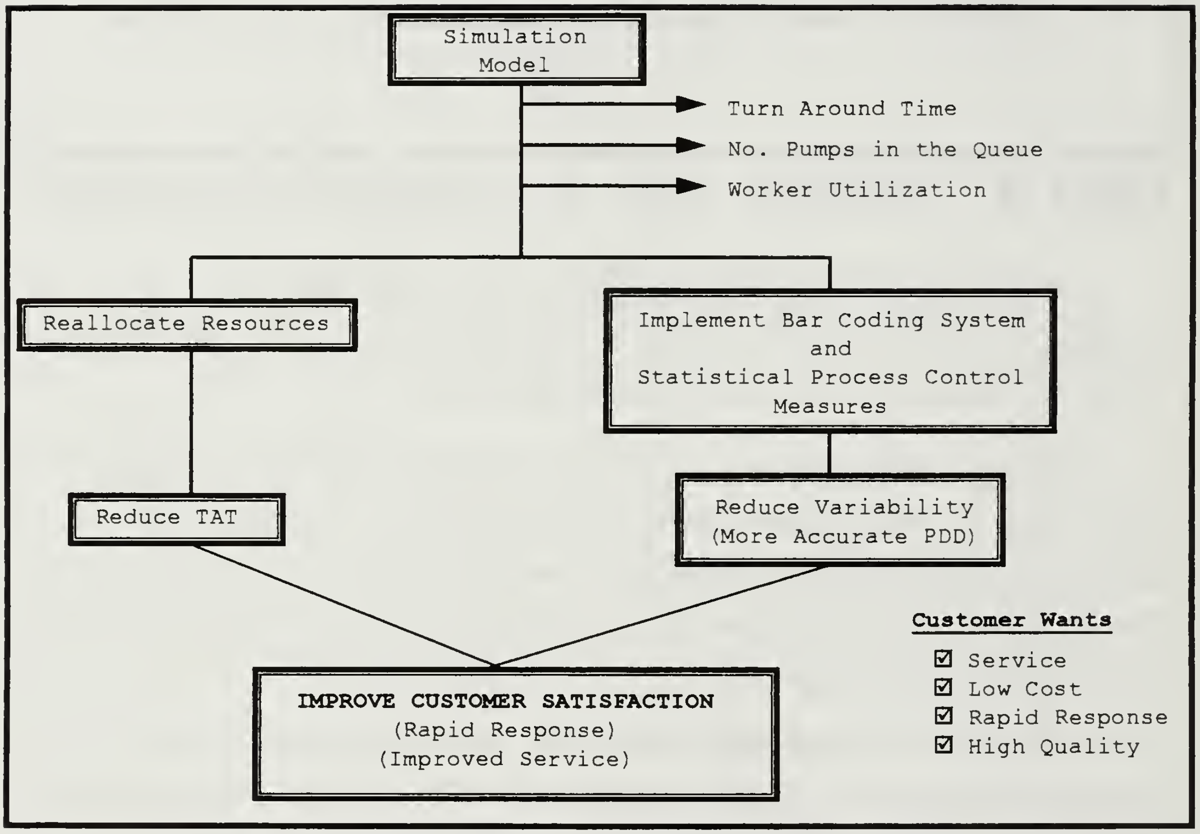

Figure 19. Relationship Between Simulation Model and Customer Satisfaction

C. RECOMMENDATIONS

The authors provide the following recommendations for implementation and further study.

PRRC management should immediately implement the PRRC simulation model presented in this thesis. This model can be used as a tool by PRRC management to assist them in evaluating the pump repair process and in making decisions concerning the allocation of limited resources.

The PRRC should immediately install the bar coding system being used in other repair shops at PSNS. With this system in place, more accurate (less variance) pump arrival rates and mean service times can be obtained. This data can be used to continuously update and further validate the PRRC model.

The measures of effectiveness developed in this thesis, *Tp* and *Pt*, should be implemented at the PRRC. These measures of effectiveness can be used by managers and P&E personnel to provide a more accurate promised delivery date, thereby improving customer satisfaction.

In order to augment the PRRC measures of effectiveness, the PRRC should adopt the use of a scientifically designed and analyzed survey of customers. This survey, taken at regular intervals, would provide valuable information about the effectiveness of the PRRC in the region.

Although one of the benefits of consolidation is reduced manpower, the PRRC needs to possess an adequate number of military mechanic billets in order not to reduce the Navy's maintenance talent pool. Sailors rotating from sea to shore must be provided the opportunity to maintain and improve their pump maintenance and repair skills. In the event this opportunity is not provided, sailors will return to sea without the intermediate level maintenance expertise necessary to support battle group operations.

A feasibility study on the use of expert systems at the PRRC should be conducted. While observing operations at the PRRC, the authors noted the vast number of specialized skills involved in repairing different pump types. The authors feel that the expertise of the pump repair artisans at the PRRC can and should be harnessed into an expert system.

Finally, an additional study should be conducted to evaluate the possibility of the PACNORWEST PRRC becoming the sole source for pump repair on the West Coast. This could be done by gathering accurate data on pump repair requirements for all platforms on the West Coast and conducting a simulation model similar to the one presented in this thesis.

APPENDIX A

MODEL:

```
14$             BEGIN,          Yes,Pacnorwest RRC;
13$             CREATE,         1:expo(14,1):MARK(Timein);
12$             ASSIGN:         jobtype=discrete(.4,1,1,2):
                                pumptype=ns:
ns=discrete(.44,1,.55,2,.58,3,.62,4,.73,5,.86,6,.90,7,.98,8,
1,9):
NEXT(goon1);
goon1           ROUTE:          expo(.13,4),seq;

rec             STATION,        receiving;
57$             QUEUE,          Receivingq,,rec;
56$             SEIZE,          1:Receiving clerk,1;
55$             DELAY:          service;
54$             RELEASE:        Receiving clerk,1;
49$             ROUTE:          expo(.13,4),seq;

dis             STATION,        disassemble;
53$             QUEUE,          Disassembleq,,dis;
52$             SEIZE,          1:Disassembler,1;
51$             DELAY:          service;
50$             RELEASE:        Disassembler,1;
48$             ROUTE:          expo(.13,4),seq;

Clean           STATION,        Cleaning;
47$             QUEUE,          cleaningq,,clean;
46$             SEIZE,          1:cleaners,1;
45$             DELAY:          service;
44$             RELEASE:        cleaners,1;
43$             ROUTE:          expo(.13,4),seq;

Inspection      STATION,        inspection;
42$             QUEUE,          inspectionq,,inspection;
41$             SEIZE,          1:inspector,1;
40$             DELAY:          service;
39$             RELEASE:        inspector,1;
38$             ROUTE:          expo(.13,4),seq;

Repair          STATION,        Repair;
37$             QUEUE,          Repairq,,repair;
36$             SEIZE,          1:Repairer,1;
35$             DELAY:          service;
34$             RELEASE:        Repairer,1:NEXT(8$);
```

```
38$           ROUTE:         expo(.13,4),seq;
Reassemble    STATION,       Reassemble;
33$           QUEUE,         Reassemblerq,,reassemble;
32$           SEIZE,         1:Reassembler,1;
31$           DELAY:         service;
30$           RELEASE:       Reassemble,1:NEXT(9$);
34$           ROUTE:         expo(.13,4),seq;

Optest        STATION,       Optest;
29$           QUEUE,         optestq,,optest;
28$           SEIZE,         1:optester,1;
27$           DELAY:         service;
26$           RELEASE:       optester,1:NEXT(1$);

1$            BRANCH,        1,1:With,.95,cont,Yes:
                             With,.05,assg,Yes;
assg          ASSIGN:        jobtype=3:NEXT(redue);
redue         COUNT:         rework jobs,1:NEXT(dis);
cont          ROUTE:         expo(.13,4),seq;

Paint         STATION,       Paint;
25$           QUEUE,         paintq,,paint;
24$           SEIZE,         1:painter,1;
23$           DELAY:         service;
22$           RELEASE:       painter,1;
21$           ROUTE:         expo(.13,4),seq;

1$            STATION,       QA:NEXT(2$);
2$            QUEUE,         qaq,,qa;
7$            SEIZE,         1:QAinspector,1;
6$            DELAY:         service;
3$            RELEASE:       qainspector,1;
5$            ROUTE:         expo(.13,4),seq;

Ship          STATION,       Ship;
20$           QUEUE,         shipq,,ship;
19$           SEIZE,         1:shipping clerk,1:NEXT(10$);
10$           DELAY:         service;
18$           RELEASE:       shipping clerk,1;
17$           ROUTE:         expo(.13,4),seq;

6$            STATION,       exitsys;
15$           TALLY:         ns,int(timein),1;
0$            TALLY:         Overall Cycle
                             Time,int(timein),1;
4$            COUNT:         jobsdone,1;
11$           DISPOSE:END;
```

Experiment:

```
BEGIN,          Yes,Yes;
PROJECT,        Regional Repair Center,
                A.Hernandez,4/25/95,Yes;
ATTRIBUTES:     1,timein:
                2,service:
                5,jobtype:
                6,pumptype;
SEEDS:          1,7548,Antithetic:
                2,7854875,No:
                4,23344567,Antithetic;
QUEUES:         1,Receivingq,LVF(jobtype):
                2,Disassembleq,LVF(jobtype):
                3,Cleaningq,LVF(jobtype):
                4,InspectionQ,LVF(jobtype):
                5,RepairQ,LVF(jobtype):
                6,Reassemblerq,LVF(jobtype):
                7,Optestq,LVF(jobtype):
                8,Paintq,LVF(jobtype):
                9,shipq,LVF(jobtype):
                10,qaq,LVF(jobtype);
RESOURCES:      1,Receiving clerk,Capacity(1,):
                2,Disassembler,Capacity(1,):
                3,Cleaners,Capacity(1,):
                4,Inspector,Capacity(1,):
                5,Repairer,Capacity(1,):
                6,Reassembler,Capacity(1,):
                7,Optester,Capacity(1,):
                8,Painter,Capacity(1,):
                9,qainspector,Capacity(1,):
                10,Shipping clerk,Capacity(1,);
STATIONS:       1,Receiving:
                2,Disassemble:
                3,Cleaning:
                4,Inspection:
                5,Repair:
                6,Reassemble:
                7,Optest:
                8,Paint:
                9,qa:
                10,ship:
                11,Exitsys;
SEQUENCES:
1,pump1,receiving,service=tria(1.4,1.7,2.4,4)&disassemble,se
rvice=tria(1.3,1.7,2.4,4)&cleaning,service=tria(1,1.5,1.8,4)
```

```
&inspection,service=tria(2.6,3,4.6,4)&repair,service=tria(3.
3,4.3,5.8,4)&Reassemble,service=tria(2.7,4.3,5.7,4)&
optest,service=tria(1.8,2,4,4)&paint,service=
tria(1,1.5,2.2,4)&QA,service=tria(1,2,3,4)&Ship,service=tria
(1,1.3,1.8,4)&exitsys:

2,pump2,receiving,service=tria(4,4.5,7.3,4)&disassemble,serv
ice=tria(4,5,6,4)&cleaning,service=tria(3,3.8,5,4)&
Inspection,service=tria(7,9,13,4)&Repair,service=tria(10,12,
17,4)&Reassemble,service=tria(7.9,9.9,13.8,4)&Optest,
service=Tria(4.8,5.8,7.8,4)&Paint,service=tria(3,3.8,5.3,4)&
QA,service=tria(1.7,2.2,3.1,4)&Ship,service=tria(1,2,3,4)&
exitsys:

3,pump3,Receiving,service=tria(17,22,31,4)&Disassemble,servi
ce=tria(17.2,21.5,30.1,4)&Cleaning,service=tria(13,16.2,22.7
,4)&Inspection,service=tria(30.6,42,55,4)&Repair,service=tri
a(42.4,52.9,74.1,4)&Reassemble,service=tria(34,47.5,59.5,4)&
Optest,service=tria(20.1,23.8,33.5,4)&Paint,service=tria(2,4
,5,4)&QA,service=tria(7,9,13,4)&Ship,service=tria(2,3,3.5,4)
&exitsys:

4,pump4,receiving,service=tria(2.5,3.1,4.4,4)&disassemble,se
rvice=tria(2.4,3,4.2,4)&cleaning,service=tria(1.8,2.3,3.2,4)
&inspection,service=tria(4.7,5.9,8.2,4)&Repair,service=tria(
5.9,7.4,10.4,4)&Reassemble,service=tria(4.8,6,8.3,4)&Optest,
service=tria(3,3.9,4.7,4)&Paint,service=tria(1,2,3.3,4)&QA,s
ervice=tria(1.2,2.3,3.2,4)&ship,service=tria(1.8,2.3,3.2,4)&
exitsys:

5,pump5,receiving,service=tria(.5,.6,.8,4)&disassemble,servi
ce=tria(.4,.5,.8,4)&cleaning,service=tria(.3,.4,.6,4)&
inspection,service=tria(.8,1.1,1.5,4)&repair,service=
tria(1.1,1.3,1.9,4)&reassemble,service=tria(.9,1.1,1.5,4)&
optest,service=tria(1,2,2.6,4)&paint,service=
Tria(.9,1,1.8,4)&QA,service=tria(.8,1.7,2,4)&ship,service=
tria(.3,.4,.6,4)&exitsys:

6,pump6,receiving,service=tria(2,2.5,3.5,4)&disassemble,serv
ice=tria(1.9,2.4,3.3,4)&cleaning,service=tria(1.4,1.8,2.5,4)
&inspection,service=tria(3.7,4.6,6.5,4)&repair,service=tria(
4.7,5.9,8.2,4)&Reassemble,service=tria(3.8,4.7,6.6,4)&optest
,service=tria(2.5,3.6,4.7,4)&paint,service=tria(1,1.5,2,4)&Q
A,service=tria(.8,1,2,4)&ship,service=tria(1,1.5,2.2,4)&
exitsys:
7,pump7,Receiving,service=tria(2,2.5,3.6,4)&Disassemble,serv
ice=tria(2,2.4,3.4,4)&Cleaning,service=tria(1.5,1.8,2.6,4)&
```

```
Inspection,service=tria(3.8,4.8,6.7,4)&Repair,service=
tria(4.8,6,8.4,4)&Reassemble,service=tria(3.9,4.8,6.8,4)&
Optest,service=tria(3.2,3.7,4.5,4)&Paint,service=tria(1,1.9,
2,4)&QA,service=tria(1,2,3,4)&ship,service=tria(.8,1,1.5,4)&
exitsys:

8,pump8,receiving,service=tria(2.3,2.9,4,4)&disassemble,serv
ice=tria(2.2,2.8,3.9,4)&cleaning,service=tria(1.7,2.1,2.9,4)
&inspection,service=tria(4.3,5.4,7.6,4)&repair,service=tria(
5.5,6.6,9.8,4)&Reassemble,service=tria(4.4,5.5,7.7,4)&optest
,service=tria(3.5,3.9,4.3,4)&paint,service=tria(.8,1.2,2,4)&
QA,service=tria(.8,1.8,2.5,4)&ship,service=tria(.8,1,1.5,4)&
exitsys:

9,pump9,receiving,service=tria(1.6,2,2.8,4)&disassemble,serv
ice=tria(1.5,1.9,2.7,4)&cleaning,service=tria(1.1,1.4,2,4)&
inspection,service=tria(3,3.7,5.2,4)&repair,service=
tria(3.7,4.7,6.5,4)&reassemble,service=tria(3,3.8,5.3,4)&
optest,service=tria(2,3.1,3.9,4)&paint,service=
tria(1,1.5,2.2,4)&QA,service=tria(.9,1.5,2,4)&ship,service=
tria(1,1.4,2,4)&exitsys;

COUNTERS:     1,jobsdone,,Yes:
              2,rework jobs,,Replicate;
TALLIES:      1,1stgpump TAT:
              2,2stgpump TAT:
              3,main feed TAT:
              4,recipump TAT:
              5,rotary pump TAT:
              6,vardispump TAT:
              7,gear pump TAT:
              8,screw pump TAT:
              9,proppump TAT:
              10,Overall Cycle Time;
DSTATS:       1,NQ(Receivingq),Receiving wip,"queue.wks":
              2,NQ(DisassembleQ),Disassembeling wip:
              3,NQ(Cleaningq),Cleaning wip:
              4,NQ(InspectionQ),Inspection WIP:
              5,NQ(RepairQ),Repair WIP:
              6,NQ(ReassemblerQ),Reassemble WIP:
              7,NQ(OptestQ),Optest WIP:
              8,NQ(paintQ),Paint wip:
              9,nq(qaq),QA WIP:
              10,NQ(SHIPQ),Ship WIP:
              11,(NR(Receiving)/1)*100,Receiver utiliztion:
DSTATS:       12,(NR(Disassembler)/1)*100,Disassembler
                  utiliztion:
```

```
                13,(NR(Cleaners)/1)*100,Cleaners utilization:
                14,(NR(Inspector)/1)*100,Inspector
                    Utilization:
                15,(NR(Repairer)/1)*100,Repairer Utilization:
                16,(NR(Reassemble)/1)*100,Reasseble
                    utilization:
                17,NR(Optester)*100,Optester Utilization:
                18,(NR(painter)/1)*100,Painter Utilazation:
                19,(NR(qa)/1)*100,QA Utilization:
                20,(NR(Shipping clerk)/1)*100,Shipping clerk
                    Utilization;
OUTPUTS:        1,tavg(1stgpump tat),"1stgta.dat":
                2,tmin(gear pump tat),"gearmi.dat":
                3,davg(disassembleq),"disq.dat":
                4,davg(receivingq),"recq.dat":
                5,davg(cleaningq),"clnq.dat":
                6,davg(inspectionq),"inspq.dat":
                7,davg(repairq),"repaq.dat":
                8,davg(reassemblerq),"reassq.dat":
                9,davg(qaq),"qaq.dat":
                10,davg(shipq),"shipq.dat":
                11,davg(paintq),"paintq.dat":
                12,davg(optestq),"opt.dat":
                13,tavg(main feed tat),"mft.dat":
                14,tavg(2stgpump tat),"2stg.dat":
                15,tavg(rotary pump tat),"rotp.dat":
                16,tavg(recipump tat),"recip.dat":
                17,tavg(vardispump tat),"var.dat":
                18,tavg(gear pump tat),"gear.dat":
                19,tavg(screw pump tat),"screw.dat":
                20,tavg(proppump tat),"prop.dat":
                21,nc(jobsdone),"jdone.dat":
                22,nc(rework jobs),"rework.dat";

REPLICATE,      10,0.0,4380,Yes,Yes,560;
End;
```

APPENDIX B

SIMAN V - License #9999999
Systems Modeling Corporation
Summary for Replication 7 of 10

Project:Regional Repair Center
Run execution date:6/4/1995
Analyst: A.Hernandez
Model revision date:4/25/1995
Replication ended at time : 4380.0
Statistics were cleared at time: 560.0
Statistics accumulated for time: 3820.0

TALLY VARIABLES:

Identifier	Avg.	Var.	Min.	Max	Observ.
1stage pump TAT	77.92	.8471	24.45	269.57	120
2stage pump TAT	104.71	.5953	58.10	241.77	33
Main Feed pump TAT	260.74	.0716	238.81	288.40	6
Recip pump TAT	79.78	.8989	38.45	239.75	13
Rotary pump TAT	75.05	1.033	11.02	275.15	30
Variable pump TAT	88.71	.8843	32.16	283.06	29
Gear pump TAT	86.54	.5770	33.74	198.32	12
Screw pump TAT	83.93	.8205	36.14	247.60	15
Propeller pump TAT	55.98	.8490	28.24	140.17	5
Overall Cycle Time	86.73	.8329	11.02	288.40	263

DISCRETE-CHANGE VARIABLES:

Identifier	Average	Variation	Minimum	Maximum
Receiving WIP	.0486	5.7186	.00000	3.0000
Disassembeling WIP	.1130	4.6154	.00000	5.0000
Cleaning WIP	.0973	5.2605	.00000	5.0000
Inspection WIP	.6175	2.5756	.00000	10.0000
Repair WIP	1.3396	1.9828	.00000	13.0000
Reassemble WIP	.9176	2.2051	.00000	10.0000
Optest WIP	.2224	3.2584	.00000	5.0000
Paint WIP	.0129	8.7224	.00000	1.0000
QA WIP	.0422	5.8857	.00000	3.0000
Ship WIP	.0088	10.6000	.00000	2.0000
Receiver Util.	20.212	1.9868	.00000	100.0000
Disassembler Util.	20.419	1.9741	.00000	100.0000
Cleaners Util.	14.995	2.3808	.00000	100.0000
Inspector Util.	36.413	1.3214	.00000	100.0000
Repairer Util.	48.812	1.0240	.00000	100.0000
Reassemble Util.	41.292	1.1923	.00000	100.0000
Optester Util.	26.246	1.6763	.00000	100.0000
Painter Util.	13.249	2.5587	.00000	100.0000

QA Util.	14.120	2.4661	.00000	100.0000
Shipping clk Util.	9.677	3.0549	.00000	100.0000

COUNTERS:

Identifier	Count	Limit
jobsdone	263	Infinite
rework jobs	11	Infinite

OUTPUTS:

Identifier	Value
tavg(1STGPUMP TAT)	77.9
tmin(GEAR PUMP TAT)	33.7
disassemble queue	.1130
davg(RECEIVINGQ)	.0486
davg(CLEANINGQ)	.0973
davg(INSPECTIONQ)	.6175
davg(REPAIRQ)	1.3396
davg(REASSEMBLERQ)	.9176
davg(QAQ)	.0088
davg(SHIPQ)	.0422
davg(PAINTQ)	.0129
davg(OPTESTQ)	.2224
tavg(MAIN FEED TAT)	260.7
tavg(2STGPUMP TAT)	104.7
tavg(ROTARY PUMP TAT)	75.5
tavg(RECIPUMP TAT)	79.7
tavg(VARDISPUMP TAT)	88.7
tavg(GEAR PUMP TAT)	86.5
tavg(SCREW PUMP TAT)	83.9
tavg(PROPPUMP TAT)	55.9
nc(JOBSDONE)	263.0
nc(REWORK JOBS)	11.0

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